SO82B Data Analysis Guide

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Table of Contents

Table of Contents

1.0 INTRODUCTION*

The sun's radiation from the atmospheric cutoff near 3000 A to 1000 A in the extreme ultraviolet (XUV) is of great interest in solar physics because it can be of assistance in explaining the physical processes by which the sun's energy is transmitted through its outer atmosphere against a steep temperature gradient. This is the region of the atmosphere where the temperature reaches its minimum value, 4400 K, between the photosphere and the chromosphere, then rises extremely rapidly as the million degree corona is approached. The spectrum from 3000 to 2100 A comes from the layers lower down than the temperature minimum, and is the usual continuum with Fraunhofer lines. From about 1535 to 1000 A the radiation originates in the chromosphere and transition region, $T \approx 20,000$ K, and its spectrum is one of intense emission lines above a weak continuum. But from 1535 to 2100 A the spectrum is an extremely complex combination of absorption lines, emission lines and continuum; this represents a mixture of radiation from layers between the temperature minimum and the chromosphere, with a number of lines from the transition region. Scattered over the entire range, 3000 to 1000 A, are the forbidden lines from the corona.

The Apollo Telescope Mount (ATM), the manned solar observatory on Skylab, provided a unique opportunity for large scale observations of the sun from above the earth's atmosphere. Supported by a coordinated program of ground-based observations, the joint observing program of its six advanced telescopes brought to bear the greatest possible observational and analytic power on fundamental problems in solar physics.

The ATM took advantage of all that had been learned from over 25 years of solar space research conducted by means of sounding rockets, Orbiting Solar Observatories (OSO's) and monitoring satellites such as SOLRAD. Each of these programs had excelled in its own particular way: rockets, for development of specialized instruments having extremely great observing power, but which were always severely limited in observing time and wavelength span, or spatial resolution or spectral resolution; OSO's not limited in observing time, but constrained in information acquisition rate, as well as in spatial and spectral resolution; SOLRAD, having excellent time resolution, but limited to broad-band detectors.

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* Material for this section has been extracted from a paper in Applied Optics, 16, 879, 1977, by J. D-F. Bartoe, G. E. Brueckner, J. D. Purcell and R. Tousey, Extreme Ultraviolet Spectrograph ATM Experiment SO82B.

These programs had established the need for continuous solar observation combining the specialized observing powers that each type of small instrument had provided. ATM came close to realizing this ideal. It provided almost continuous observation of the solar atmosphere for a period instrument was enormous. In addition, by fostering the simultaneous operation of the newest and most powerful ground-based observational techniques, the total resulting program represented a massive attack on the problems in solar physics, resembling that mounted during the IGY for geophysics.

This Guide has been prepared to assist callaboration in the analysis of SO82B data, especially from copies of the data supplied through the National Space Science Data Center through the National Space Science Data Center at NASA/GSFC. We have found, however; that by gathering the most useful data into one source, it is of benefit to any researchers who may be familiar with the general experiment but not with the specific details required in making a study of the data. Therefore, a brief description of the experiment, the instrument, and supporting features of ATM and the Skylab program have been included in addition to specific details of the calibration of film and instrument.

An extensive bibliography of papers by the NRL ATM analysis team is given in the Appendix indicating fruitful directions of research provided by the data and those staff members knowledgeable in specific areas.

A list of documentation references, the catalog of exposures (on microfiche), a wavelength scale, and line lists to assist in identification of lines are also included.

Requests for information about callaborating with NRL may be directed to specific members of the data reduction team whose names appear on related publications listed in the Bibliography. Access to original flight data and supporting material may be arranged by contacting Dr. Richard Tousey, Principal Investigator.

2.0 THE APOLLO TELESCOPE MOUNT*

Skylab consisted of four principal parts. Largest was the Saturn Workshop (SWS), which provided living and working quarters for the three-man crews. It contained also most of the experiments other than the ATM. The hydrogen tank of a Saturn IVB booster (second stage of of Saturn IB) that was converted to become the SWS was a cyclinder 15 m long and 6.7 m in diameter.

The second major section was the Multiple Docking Adapter (MDA), center of the space complex, 5.2 m long and 3.2 m in diameter. This was attached to the SWS through an airlock module (AM) and contained the control and display panel for the ATM. It had two docking ports: the first port, located on the long axis extending through the AWS, was for docking the CSM when on each visitation it came up with its crew of three; the second port, 90 away, was an alternate dock for a rescue mission, should it be required. Opposite the latter port was the ATM. The third part was the CSM itself, much the same as the Apollo Spacecraft developed for the lunar landings.

The ATM and its solar instruments are shown in Fig. 2.1. It consisted of two concentric elements: the outer framework, or rack, an octagonal structure 3.4 m across and 4.4 m in length, and inside the rack a cyclinder or canister, 2.1 m in diameter and 3 m in length. The canister housed the solar instruments. It was attached to the rack through a pair of large gimbal rings carried on a large ring bearing, which allowed rotation of the entire canister around its axis. A stiff cruciform structure divided the space into four quadrants and formed the optical bench to which the ATM instruments were attached.

The ATM was designed to keep the instruments within the cannister aimed steadily and precisely at the desired point on the sun regardless of disturbances such as those caused by crew movement, within ± 2.5 arc sec in yaw and pitch and 5 arc min in roll. These specifications were actually exceeded in flight. Short-time (minutes) yaw and pitch stability was ± 0.5 arc sec, and short-time roll stability was excellent. Part of the success in stability control was derived from the 3 arc min stability of the entire Skylab, accomplished by an orthogonal system of control moment gyros (CMG).

Fine pointing of the ATM was accomplished with a solar pointing control system (PCS), which sensed the Sun's center to a few tenths of an arc sec and sent error signals

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into the torque motors that controlled the rotational
positions of the ATM canister gimbals. Offset pointing of
the ATM in yaw or in pitch by steps of 1.25 arc sec up to
24 arc min could be introduced by counter-rotating a pair
of quartz wedges placed in the solar beam incident on either
the pitch or the yaw solar sensors. Rotation of the prisms
was accomplished by a crewman with his panel "joystick".
Digital indicators read out yaw and pitch to 1 arc sec, and
roll to 1 arc min.

A most important subsystem was the digital computer. It
enabled the crewman to initiate complex commands simply.
The computer could also be operated by ground command, while
the crew was sleeping, or in case of emergency. Thus many
experiments were operated while the crew were asleep, and
also during the unmanned periods between missions.

A problem in the design of the ATM was the great thermal
stability required to preserve the focus of the ultrahigh
resolution optical instruments. Passive thermal stabiliza-
tion alone was not sufficient to meet the requirements and
was augmented by an active fluid-cooling system for the ATM
canister. The refrigerator consisted of a loop, located
inside the skin of the canister, through which water and
methanol was circulated to radiators on the outside of the
canister, facing space. This system maintained the tempera-
ture of the canister wall to $50 \pm 5^{\circ}$ F with cyclic variations
of $\pm 3^{\circ}$ F. In addition, several experiments had their own
thermal-control heater systems, designed to maintain the
temperature at all locations to within 2.5° F of the design
and calibration temperature and to limit the rate of change
to no greater than 0.05° F per 5 minutes.

2.1 The Solar Instruments

Table 2.1 summarizes the major solar experiments and
instrumentation mounted in the ATM. Brief sketches of these
are given below.

SO52: White light Coronagraph

The white light coronagraph on Skylab was designed
by the High Altitude Observatory of the National Center
for Atmospheric Research. The scientific goal of the SO52
instrument was the observation of the outer corona from
about 0.5 solar radius ($R_{\odot}$) to $5R_{\odot}$ above the solar limb,
with high spatial and temporal resolution, and from
these data to deduce the 3-D form of the corona and its
evolution and rapid change. These photographs from Skylab
form a nearly continuous record of the corona for 9 months
that is of the character observed for only a few minutes
once each year or two at natural eclipse. More than 35,000
useful photographs were secured, including coverage of more
than 100 transient eruptions in the corona.

SO54:   X-Ray Spectrographic Telescope

The American Science and Engineering Corporation
(AS&E) and the Goddard Space Flight Center (GSFC) jointly
pioneered the use of the Wolter lens, grazing-incidence
telescope for imaging the sun in X-rays.

The instrument flown in ATM by AS&E employed a Wolter
lens and was equipped with six filters, each with a
different transmittance curve. It was also possible to
introduce a 1440-lines/mm transmission grating into the
beam and thus obtain low resolution spectra of small
bright features such as flares. Limited operation was
carried on in the unattended and unmanned modes. A total
of 31,785 exposures were made, with times ranging from
1/64 sec to 256 sec. Soft X-ray images from this telescope
show in a most spectacular fashion the coronal holes,
where the high speed solar wind streams originate.

SO56:   X-Ray Telescope

The GSFC also utilized a Wolter lens-type telescopic
camera for ATM. In dimensions and general characteristics
SO56 and SO54 were much alike. The principal difference
between them was that SO56 had some three times less light
gathering area, but was equipped with a different series
of filters, which enabled it to record somewhat harder
X-rays . Although the instrument was operated only in the
manned mode, 27,972 excellent X-ray images were secured.
It was particularly successful in recording images of high
spatial resolution, which showed the growth phase of flares
in detail.

SO55:   Ultraviolet Spectrometer-Spectroheliometer

The Harvard College Observatory spectrometer and
spectroheliometer was designed to secure calibrated EUV
spectra and images of selected portions of the solar disk
in the light of a number of strong emission lines. The
lines were chosen to sample a broad range of solar
temperatures, from the middle chromosphere to the low
corona. Detection was entirely photoelectric using seven,
independent, open-channel, electron multipliers in a
variety of ways. Four modes of operation were available:
(1) the spectrum of a selected 5 x 5-sec arc solar area
could be scanned in 3.8 min with a resolution of 1.6 A;
(2) the readings from the seven multipliers, set at seven
important wavelengths ranging from 280 A to 1350 A, could
be read out as functions of time with 40-msec time resolu-
tion; (3) the sun could be recorded at seven wavelengths
but with the instrument scanning a line 5 sec of arc wide
and 5 min of arc long once in 5 sec, or; (4) a 5 x 5-min
of arc area could be scanned with 5 x 5-sec of arc spatial
resolution in 5 min at seven wavelengths. The instrument

was operated in both unattended and unmanned modes, but without the capability of fine pointing except when manned and with a crewman in charge. Excellent results were obtained with intensity data covering a wide dynamic range with high precision.

SO82A: Extreme Ultraviolet Spectroheliograph

The XUV spectroheliograph of the Naval Research Laboratory was an objective grating instrument which produced simultaneous, monochromatic images of the entire sun over a broad range of the XUV. Over the 171-630-A range a spectrum of solar images each 18.6 mm in diameter was recorded. The instrument produced results of extreme interest and acquired a total of 1032 useful exposures.

SO82B: Ultraviolet Spectrograph

A type of solar observation considered of great importance was the recording of the XUV spectrum at great spectral and spatial resolution for different kinds of solar regions, for example, filaments, active regions, the limb, flares, and so on. The large NRL spectrograph was designed for this purpose. Being a photographic instrument, it had tremendous information-gathering ability. The short wavelength range covered the XUV from 970 A to 1970 A with a spectral resolution of 0.06 A, which was sufficient to obtain useful line profiles. The long wavelength range extended from 1940 A to 3940 A with 0.12 A spectral resolution. Photoelectric servo-control of the primary mirror was provided to enable the 2-sec of arc wide slit to be stepped across the limb at intervals of 1 sec of arc. The slit was also equipped with an imaging system which allowed the crewman to see exactly where the sun's limb fell on the slit plate relative to the slit in order to calibrate the automatic image-positioning device. The instrument suffered principally from having too long a slit to isolate sufficiently the smallest solar features, but it performed very well, and 6400 spectra were obtained.

The NRL photographic and HCO photoelectric instruments complemented each other in many ways. The spectral range covered by HCO, nominally 280-1350 A, overlapped generously NRL's SO82A range, 171-630 A, and SO82B's range, 970-3940 A. The advantages of photoelectric over photographic recording are the increased precision of the intensity measurements and the wider dynamic range covered. Photographic recording, on the other hand, is capable of gathering information far more rapidly than photoelectric, but to cover a large dynamic range requires making a series of exposures covering a wide range of times. In temporal resolution photoelectric recording is superior;

photographic excels in spatial and spectral resolution. To the greatest extent practicable SO55, SO82A and B were operated together.

2.2 Supporting Instrumentation

Each group of ATM experimenters recognized the need for supporting instrumentation of various kinds in order to make optimum use of the six major solar instruments. The supporting instruments fall into several classes as follows:

(1) Instruments to enable the crewman to point the ATM at a pre-selected solar position with pre-selected roll, with coordinate values displayed on-board, and telemetered to ground.

(2) Instruments to present solar images to the crewman in various wavelength bands, to enable him to point the ATM at features of interest that he could see.

(3) Instruments to alert the crew to the occurrence of a solar flare so that they could initiate observing programs, and also instruments to assist in anticipating the occurrence of a solar flare.

The H-Alpha Telescopes

The two H-α telescopes were the most useful devices for showing the crewmen the precise pointing of the ATM relative to features on the solar disk and for recording this position. A spectral resolution of 0.7 A was achieved with Fabry-Perot-type filters. This assured maximum visibility of solar flares and the chromospheric network. Zoom lenses were arranged to provide optical telescopic systems which could be used at low or high magnification, with a resolution of 1 to 2 arc sec at the high setting. The ATM control and display (C+D) panel was equipped with two identical cathode ray tube monitors of six inches diameter, each with an electronic reticle. The images produced by the two H-α telescopes could be presented on either of these scopes, and any other TV-type image such as the XUV monitor image could also be presented. It was thus also possible to view at the same time a highly magnified image of a small part of the sun and an image of the entire sun.

H-α #1 was equipped with a camera for recording photographically on 35 mm film the H-α solar image as projected on the SO55 slit with 1 arc sec spatial resolution. A mechanically-movable reticle system adjusted to the relative co-alignment between SO55 and SO82B then made it possible to record the precise positions of both SO82B and SO55.

H-α #2 was not equipped with photographic recording, and was used mainly to present for study by the crewman a high quality H-α image of the entire sun. Like H-α #1 it was equipped with a movable reticle that was visible in the image of the CRT, and could be zoomed to high magnification. Therefore it also could be used for pointing.

White Light Solar Pointing Devices

There were several instruments that imaged the sun in white light and could be used for establishing and recording solar pointing coordinates. The principal device was the optical pointing control system (PCS), described earlier. This was designed to point the entire ATM at any desired angles in pitch and yaw relative to the solar center with an accuracy of 1.25 arc sec. The pointing coordinates were displayed on the C&D panel and were also transmitted by telemetry for recording on the ground. In addition, they were recorded on the ends of the film strips of SO82A and B by photography of a photodiode matrix built into each of these instruments. Additional pointing information was given by the special white light pointing error sensor built into SO52 for the purpose of aligning the external and internal occulters and the entire instrument.

Roll, however, could not be established as easily and accurately as yaw and pitch. Several methods were available. One utiilized the Skylab rate-gyro system which operated together with the CMG's to stabilize the entire Skylab. A possible but little used method was to observe a sunspot in the white light image projected on the SO82B slit and displayed on one of the CRTs of the C&D panel. The most precise information was given by a star tracker mounted on the ATM. The star tracker measured the angle between Canopus or certain other stars and the ATM yaw and pitch directions.

The XUV Monitor

The XUV monitor of NRL was a device which showed the crew in real time a visible image of the sun produced by its emission in the extreme ultraviolet band 171-500 A, approximately. This band included radiation from the corona and transition layer, with a contribution of about 20% from the chromosphere. The monitor was equipped with a reticle circle and cross that permitted it to be used for pointing with a spatial resolution of 15-20 arc sec. The pattern of features and their intensities on this monitor were more nearly like those of the radiation studied by the solar instruments than was the pattern of emission shown by the H-α telescopes. The XUV images were transmitted by TV to the ground several times a day for use by the ATM PI's in planning the observing programs. A file

of the ground pictures plus polaroid exposures of the on-board moniitor is available for study at NRL. The XUV monitor was extremely valuable for predicting and locating the occurrence of a solar flare and was also found most useful for locating boundaries of coronal holes and bright points in both active regions and the network.

X-Ray Detectors

As part of MSFC's SO56 there was included a device known as the X-ray Event Analyzer (XREA). Its purpose was to measure the total X-ray flux emitted in the band 2.5-20 A, or 5-20 A and 27-33 A. The detecting system made use of two proportional counters with pulse-height analyzers and data processing for display to the crewman and for telemetry to the ground.

Another device somewhat similar to the XREA was the Photomultiplier Exposure Counter (PMEC), constructed by AS&E for use with SO54. This used a photo-multiplier to count the scintillations produced by X-rays in a NaI: Tℓ crystal that viewed the entire solar flux. It was equipped with filters that restricted its sensitivity to the hard X-ray spectrum. A range of five decades of intensity was converted by compression into a decimal range of 0-1000 counts per sec.

Still another X-ray detector was the X-ray imaging system constructed by AS&E. This consisted of a small Wolter lens which imaged the sun in X-rays onto a thin scintillator crystal. The visible light scintillations emitted by this crystal were detected by an image dissector tube which scanned the image and displayed the X-ray sun on a separate small CRT on the C&D panel. This image allowed the crewman to determine which active region was flaring. The principal use made of this system, however, was for display of the X-ray count level being detected by the IDT.

All three systems were used to record the solar X-ray flux and to alert the crew to an increase in flux level of magnitude sufficient to suggest that a flare might be expected or that a flare was in progress. The data collected by the XREA and by the PMEC were of great value to the principal investigator teams in connection with planning during the mission and are also useful in the interpretation of results. They supplement X-ray flux measurements made by other systems, such as the NRL SOLRAD 9 and 10 solar monitoring satellites.

The Radio Noise Burst Monitor

The solar radio noise burst monitor provided monitoring of the radio bursts emitted by the whole sun in the 6 cm band. These radio bursts are sometimes precursors of flares. The monitor consisted of a receiver and display that showed on a meter above the C&D panel the level of noise in units of solar radio flux. This device could also be used to activate an audible alarm system to the crew when the flux exceeded a certain threshold value.

Figure Captions

Fig. 2.1   A sketch of the Apollo Telescope Mount.   Three of
          the instruments can be seen attached to the central
          cruciform supporting structure.

APOLLO TELESCOPE MOUNT (ATM)
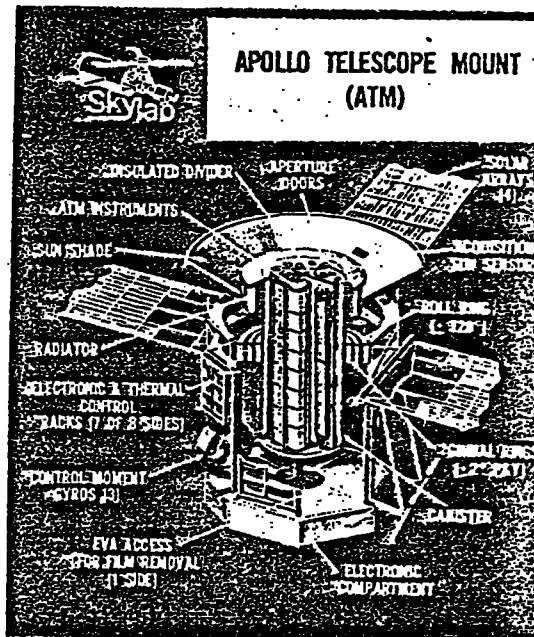
Fig. 2.1 A sketch of the Apollo Telescope Mount. Three of the instruments can be seen attached to the central cruciform supporting structure.

Table 2.1

Table 1. Summary of ATM Instruments

Name and number	Institution P.I. (mission)	Wavelength range	Wavelength resolution	Spatial resolution	Field of view	Temporal resolution	Recording	Manned (M) unmanned (UM) unattended (UA)
White light coronagraph S052	HAO R. M. MacQueen	3700–7000 Å	—	8.2"	1.5–6 R	≥40 sec	Photographic, TV & TM	M, UM, UA
UV spectrograph S082B	NRL R. Tousey	3940–1940 Å 1970–970 Å	0.12 Å 0.06 Å	2" × 60" 2" × 60"	Anywhere within ±24' of sun ctr.	>0.15 sec	Photographic	M
EUV spectrometer-spectroheliometer S055	HCO E. M. Reeves	1350–280 Å	1.6 Å	5" × 5"	5' × 5' 5' × 5' 5" × 5"	5 m 5 sec 40 msec	Photoelectric and TM	M, UM, UA
XUV spectroheliograph S082A	NRL R. Tousey	630–171 Å	0.025 Å	2.5" × 2.5"	57' × ~60'	≥2.0 sec	Photographic	M, UA
X-ray spectrographic telescope S054 S054	AS&E G. Vaiana	60–3.5 Å	Bands grating: 0.15 Å at 7 Å	~2"	48' diam	≥2.5 sec	Photographic	M, UM, UA
X-ray telescope S056	MSFC J. E. Milligan	53–3 Å	Bands	~2"	38' diam	≥3.5 sec	Photographic	M, UA
H-α #1	HCO E. M. Reeves	6563 ± 0.35 Å	—	~1"	16–4.4'	1/30 sec	Photographic TV & TM	M, UM, UA
H-α #2	MSFC P. Hassler, Jr.	6563 ± 0.35 Å	—	~1"	35–7'	1/30 sec	TV & TM	M
XUV monitor	NRL R. Tousey	171–500 Å	None	15" × 15"	56' diam	1/30 sec to 4 sec	TV & TM	M
X-ray scope	AS&E G. Vaiana	2–10 Å 0–8 Å	None	1'	48' diam	~1 sec	TV & digital	M
PMEC	AS&E G. Vaiana	0–8 Å	Pulse height	None	Full sun	Continuous	Digital & TM	M, UM, UA
XREA	MSFC J. E. Milligan	2.5–33 Å	Pulse height	None	Full sun	Continuous	Digital & TM	M, UA
RNBM	MSFC O. K. Garriott	6 cm		None	Full sun	Continuous	Meter	M

3.0 THE SO82B INSTRUMENT*

The large NRL spectrograph used for Experiment SO82B was a photographic instrument similar to those flown in rockets by NRL from 1960 to 1966. The short wavelength range covered the XUV from 970 to 1970 A with a spectral resolution of 0.06 A, which was sufficient to obtain useful line profiles. The long wavelength range extended from 1940 to 3940 A with 0.12 A spectral resolution. Double dispersion was used to reduce the focused straylight from the long wavelength part of the solar spectrum, which at 5000 A is 10^4 more intense than at 1500 A.

To obtain sufficiently high spatial resolution a primary mirror was used to image the sun on the spectrograph slit. In this way a solar element 2 arc sec wide and 60 arc sec long was resolved. The mirror added a third reflecting surface, however, which greatly reduced the speed of the system at wavelengths less than 1100A, the short wavelength end of the range where high reflectance coatings are available. To compensate for this and to increase the speed generally, the instrumental astigmatism and therefore the lengths of the spectral lines were reduced.

Photoelectric servo-control of the primary mirror was provided to enable the 2 arc sec wide slit to be stepped across the limb at intervals of 1 arc sec. The slit was also equipped with an imaging system which allowed the crewman to see exactly where the sun's limb fell on the slit plate relative to the slit in order to calibrate the automatic image-positioning device. The instrument suffered principally from having too long a slit to isolate sufficiently the smallest solar features.

Temporal resolution achievable was approximately 1 min, sufficient to follow the change in the spectrum during the flash phase of a flare, or to search for oscillations of a 5 minute period in the low chromosphere.

3.1 General Description

The overall optical system of the XUV solar spectrograph is shown in perspective in Fig. 3.1. It consisted of a single mirror telescope and a double grating spectrograph.

The spectrograph directed the light passing through the slit to one of two interchangeable predisperser gratings, which selected the short or long wavelength band reaching the main grating through the waveband aperture.

The main grating was concave with 2000 mm radius of curvature, 600 lines per mm, and 76 x 152 mm clear aperture. The second order of this grating was used to cover the spectral range 970-1970 A. This was selected by means of a 500 mm radius predisperser grating having 300 lines per mm. When used in the first order the range 1940-3940 A was selected by a predisperser ruled with 150 lines per mm. Each predisperser was ruled in 10 parts, for each of which the spacing was changed slightly to introduce a change in sagittal focus just sufficient to compensate for the astigmatism of the main grating.

The dispersion of the spectrograph was 8.3 A/mm and 4.2 A/mm in the long and short wavelength modes, respectively. The spectral resolution was ≈ 0.05 A at 1500 A and ≈ 0.10 A at 3000 A. The spatial resolution, determined by the slit and mirror, was 2 x 60 arc sec.

Photographic films used were Eastman Kodak Schumann-emulsions, mainly type 104, but with some of the more sensitive type 201. A camera magazine held 201 film strips, each of which could be moved to 8 positions, permitting the exposure of 1608 spectra per camera. A small chip of fast, red sensitive film was placed at the end of each film strip for recording essential exposure data displayed in binary code on a diode array flasher.

3.2   The Telescope and Pointing

The telescope mirror was an off-axis paraboloid, of 1 m focal length and 54 x 121 mm clear aperture. The mirror formed on the entrance slit of the spectrograph a solar image of 9.3 mm diameter, with a resolution of approximately 1 arc sec, close to diffraction limited as measured with visible light.

Figure 3.2 shows the telescope and the pointing reference system. The telescope mirror was mounted on a one axis pivot system which permitted it to be rotated by a servo motor about an axis parallel to the slit. This motion allowed the sun's limb to be aligned more precisely with respect to the spectrograph slit, and provided greater pointing stability in one axis than was achievable with the ATM pointing system alone.

The stability in one axis was thereby increased to ≤ ± 1 arc sec with a jitter ≤ ± 1 arc sec per sec. In laboratory tests the servo system was able to maintain this pointing accuracy when exposed to drift rates as high as 14 arc sec per sec. In addition, the pointing reference system could position the solar limb at any angle with respect to the spectrograph slit over a range of ± 70 arc sec with an accuracy of 1 arc sec.

The servo loop was controlled by an image dissector tube (IDT), which received an image of the sun reflected by the slit plate. The slit plate itself was a thin film of nickel over copper with a 10 micron by 300 micron slit etched through it. In addition, fiducial marks were etched into the nickel layer only. These fiducial marks were used by the pointing reference system electronics to determine the position of the solar limb with respect to the slit. The slit plate and its slit were designed to conduct away the heat produced by the solar image.

In the "limb pointing" mode, the system was under servo control. The "boresight" mode was used for manual pointing of the spectrograph, for checking coalignment with the other ATM instruments and especially the ATM pointing control system (PCS), and for locating sunspots. In the latter mode, the IDT output from the whitelight solar image on the slit plate was displayed on one of the CRT's at the C&D panel.

Researchers who need to know the location on the sun of a particular exposure must refer to supplementary documentation listed in Appendix A. The most directly useful of these is the Harvard ATM H-Alpha Atlas and Atlas Guide (#11), which gives a print of the sun exposued in $H\alpha$ as projected on the SO55 slit, with the position of the SO82B slit indicated. The appropriate orientation coordinates are also given. In addition to the selected Atlas prints made for each ATM pointing change, all $H\alpha$ exposures made from Skylab are available separately on 35 mm film. See also a description of the H-alpha telescopes in Section 2.2.

3.3 Astigmatism, Spectral Resolution, and Stray Light

By the introduction of the telescope mirror to the spectrograph design, small regions of the sun could be studied quantitatively, an advantage over earlier rocket instruments. In the former instruments the predispenser gratings served to form a very small image of the sun on the slit, and were also slightly deformed to neutralize the astigmatism of the main grating. By ruling a special type of predisperser for SO82B, instrumental astigmatism was reduced and speed was increased to offset the loss incurred by the third reflection of the telescope.

Figure 3.3 illustrates the astigmatism acquired by use of the Rowland mounting for a grating. With the rulings of the grating perpendicular to the plane of the paper, the tangential focus of the diffracted slit image from A lies on the Rowland circle at B, where the slit width is in focus. The sagittal focus, or focus of the slit length, lies on a line perpendicular to the grating normal and tangent to the Rowland circle as at point C.

This is known as Sirk's position. A converse arrangement
with the tangential focus at point B and the sagittal focus
focus at point C should produce a stigmatic image at point
A.   The predispersers of the ATM spectrograph were designed
to approximate this special condition. The idea was to make
use of the change in sagittal focus of a concave spherical
grating, secured by continuously changing the grating spacing
in the proper way during ruling. This property of a grating
has been known for some years in connection with grating
errors; it had never been made use of in spectrograph design.
To rule such a grating would have required development of a
device by means of which the grating spacing could be changed
continuously and precisely. It was possible, however, to
approximate the continuous change with a multipartite grating,
ruled in ten 40 mm long and 3.6-mm wide segments, each having
a slightly different ruling spacing. In the reduction of
the astigmatism the spectrum was narrowed, and an increase
in speed of the instrument was obtained.

Figure 3.4 illustrates the effect of the segmented
predisperser. Diffracted rays from each segment come to
a tangential focus on the Rowland circle of the predisperser
grating, as in a conventional Rowland mount. However, the
ray bundles from different panels cross each other at point
C before they reach the Rowland circle of the predisperser.
Thus a pseudotangential focus is formed at point C. The
sagittal focus of each panel still occurs along the predis-
perser's sagittal focal plane in the vicinity of point B.
Therefore the slit width is in focus at point B, while the
slit length is in pseudofocus at point C, the Sirk's posi-
tion for the main grating.

The size of the clear aperture of the telescope mirror
allowed only the central eight segments to be illuminated.
As shown in Fig. 3.5, the diffracted beam from these eight
perdisperser panels considerably overfilled the main grating.
For any particular wavelength, only five adjacent predisper-
ser panels, or four plus a half panel at each end, illuminated
the main grating. This permitted the optimization to be made
over a greater range of wavelengths because different seg-
ments were used at, say, 1200 A than at 1800 A. The ruling
spacing of each predisperser segment was chosen to optimize
the distance between points C and B for the different parts
of the wavelength range. Figure 3.6 shows the astigmatism
at the film plane for both uniformly ruled and segmented
predispersers as a function of wavelength. The spectrum
height for the case of the segmented predisperser on the
average is one-fourth that for the uniformly ruled predis-
perser. Thus the instrument speed was increased by about
a factor of 4. Without this increase in speed, the long
exposure times necessary to obtain the weaker lines and
continua of the solar XUV spectra, particularly for record-
ing spectra above the solar limb, would have been too long
for practical application on Skylab.

Although the segmented predisperser increased the instrument speed, it degraded slightly the spectral resol-resolution at the film plane. This was caused by the off-plane aberrations of the Rowland mounting. As Fig. 3.7(a) illustrates, the beam incident on the main grating was not parallel to the plane of the main grating's Rowland circle, and the departure was a function of wavelength. Point B is the sagittal focus of the predisperser; it is also the point at which the main grating Rowland circle intercepts the plane of the figure. The line at point B defining the extent of the beam diverging from C is not centered with the Rowland circle plane, and the beam incident on the main grating is inclined with respect to this plane.

Thus the main grating is used off-plane. Figure 3.7 (b) illustrates a conventional Rowland mounting with an off-plane slit source; Fig. 3.7(c) shows the curved and tilted line image of the slit that is produced. The aberrations are exaggerated and not to scale. When the segmented predisperser is used, each segment illuminates the main grating at a slightly different angle in such a way that the final image is compressed; however, the compressed portions are not in precise registration in the lateral direction, as illustrated in Fig. 3.7(d). Hence, the spectral resolution is degraded.

Figure 3.8 shows the spectral resolution at the film plane as measured from laboratory spectra. The upper and lower curves apply, respectively, to the short and long wavelength ranges of the instrument. Photometrically determined full widths at half maximum were used to obtain the measured points. For comparison, the theoretically attainable resolution, as derived from a 3-D ray tracing computer program, is indicated by the solid line. For the most part, the spectral resolution is 30,000, but is decreased to 20,000 at the short wavelength end because of the off-plane aberrations. The spectral resolution of the instrument achieved during flight agreed well with the preflight laboratory measurements.

A shortcoming in this design of a double-dispersion, dual predisperser spectrograph lay in the use of the second order of the main grating in combination with the first order of the 300-1/mm predisperser. The focused stray light from the predisperser that included all wave-lengths came to a vertical linear focus on the waveband aperture; this aperture allowed a significant fraction to pass through and onto the main grating. The main grating, in turn, brought the long wavelength portion of the stray light to focus in its first order. Therefore, the desired spectrum, 977-1970 A, was overlaid with a broad, faint spectrum of 1954-3940 A wavelength, whose height was deter-mined by the waveband aperture. This unwanted spectrum was

of greater intensity relative to the XUV for spectra of regions on the sun's disk than for positions close to or above the limb. It became insignificant at wavelengths shorter than 1500 A. The predisperser grating was ruled in a way that minimized the focused stray light.

3.4   Optical Coatings

The optical surfaces were coated to provide the maximum reflectance possible for the short wavelength band and to reduce the speed in the long wavelength band where the solar intensity is so great. Figure 3.9 lists the coatings on each element and shows the total instrument reflectance, including the efficiencies of the gratings.

In order to obtain the maximum possible efficiency at the short wavelengths where the solar spectrum is weakest, the 300-1/mm predisperser and the main grating were blazed at 1200 A. The peak in the instrument reflectance at about 1300 A shows the effect of the blaze. The sudden decrease in reflectance below 1200 A was caused mainly by the decreasing reflectance of the magnesium fluoride; it was especially prominent because the beam was reflected by three such surfaces. The minimum at 2900 A is a characteristic of the multilayer Al-ZnS coating.

3.5   Thermal Control System

In order to maintain good focus and to avoid smearing the image, the over-all temperature of the spectrograph was maintained between 20.9° C and 21.2° C, and the local thermal differences were held to less than 0.2° C, although the temperature of the ATM canister ranged from 10 C to 27° C and that of the ATM spar from 16° C to 21° C. Prior to installation in the ATM, the instrument was focused at 21° C. A combination of passive thermal shielding and active thermal control panels was used to control the over-all temperature.

Prevention of direct heating by the incident solar radiation was accomplished mainly by a mirror that encircled the slit plate. This mirror reflected the portion of the solar image not striking the slit plate back to the telescope mirror and out the front aperture. In addition, there was a heat rejection mirror surrounding the perimeter of the telescope mirror; this reflected out the front aperture any radiation that overfilled the mirror. These heat rejection mirrors kept differential heating of the instrument at a minimum, thus preventing significant smearing of the final image at the film plane during long exposures.

3.6   Film and Film Camera

Kodak Special Film types 104 and 101 were used. Both are VUV sensitive Schumann emulsions deposited on a thick gelatin pad carried on a 7-mil Estar base. The gelatin pad between the base and the emulsion contained a yellow antihalation dye to absorb scattered solar radiation longer than 2500 A.

From 1000 A to 4000 A type 101 film is approximately two to five times faster than type 104. However, tests conducted prior to the Skylab mission revealed that type 101 film is disproportionately more susceptible than 104 to environmental effects. Therefore, the majority of the film strips used in the cameras were of type 104.

When received from Kodak, the film was in 100-ft rolls, 70 mm wide. Due to the great sensitivity to abrasion of these emulsions, each turn on the roll was separated from its neighbors by raised rails that consisted of a band of polystyrene beads secured to the gelatin and placed along each edge of the film. The strips of film for the spectrograph, measuring 35 mm x 250 mm, were cut from the center of the 70-mm wide rolls and mounted in flexible anodized aluminum holders. A chip of Kodak Plus-x panchromatic film was mounted at the end of each holder to record the diode matrix flasher exposure data. Two examples of the film strips and chips are shown in Fig. 10. Eight solar spectra and the diode array data exposures can be seen on each strip. The top strip is a flare spectrum in the short wavelength region (970-1970 A). The bottom is a limb scan exposure sequence containing both long and short wavelength spectra.

The camera carried 201 holders which were stacked in two columns of 100 each, one column above the other. As the camera was cycled, the perimeter of the strip to be exposed was pressed against a carrier which was shaped to the Rowland circle focal plane of the main grating and was registered to within 0.1 mm. The carrier was transported parallel to its long dimension in 3-mm steps, thus allowing eight exposures to be recorded on each strip. The camera was mounted to the instrument, as shown in Fig. 3.11, by a latch and guide rail system which provided easy installation and removal by the astronaut while maintaining accurate registration with the focal plane. Prior to being mounted in the instrument, the camera was stored in a sealed canister filled with nitrogen. After use on the instrument, the camera was returned to the canister and sealed while in the space vacuum.

3.7   Instrument Performance

The spectrograph operated well over the entire Skylab mission. There were no anomalies, except those connected with Schumann film, which are described elsewhere in this Guide (Sec. 4). One camera was exposed during SL-2, two during SL-3, and one on SL-4. A total of 6408 spectra was obtained.

In Fig. 3.12 there is reproduced a sample section of eight exposures made at the beginning of the first mission. This shows the 1170-1245 A region, less than 10% of the entire coverage in the short wavlength position. These exposures were made in the automatic limb scan mode. Exposures of 160 sec were made between the white light limb and -12 sec of arc inside. The exposures made above the limb to +8 sec of arc were four times longer. This limb scan was carried out when an active region was on the limb.

The Lyman-α line of hydrogen, 1216 A, is seen to reach greatest intensity in the chromosphere, 2 sec of arc above the limb. All images of it are greatly overexposed. The profile of the line is conspicuous; broad wings, the central maximum doubled by deep self-reversal caused mainly by the great optical density of the solar atmosphere at the center of the line and also by the telluric hydrogen absorption core. When observed close to the limb, the double peaks became so intense that their images were solarized. Between the solarized images one can see an extremely narrow non-solarized line; this is the telluric absorption core, whose width is 0.025 A. The other chromospheric and low transition region lines, Si II, Si III, C III, N V, maximize at the same limb position, approximately, as does Ly-α.

The behavior of the coronal and high transition region lines is different. For example, Fe XII, 1242.0 A, is extremely faint on the disk at -12 sec of arc. It is most intense above the limb and stays intense all the way to +8 sec of arc above the limb.

Shown on Figure 3.12 are several lines whose identifications are new*. Mg VII, 1189.8 A, S X, 1196.2 A and 1213.0 A, S V, 1199.2 A, and Fe XIII, 1216.4 A. In older low dispersion spectra the intersystem line O V, 1218.4 A was barely visible above the Lyman-α wing, much as is the case in Fig. 3.12 for Fe XIII, 1216.4 A, which is three times closer to Ly-α than O V.

Within the 1000-A short wavelength coverage of the spectrograph approximately 4000 lines can be resolved. Some 50% have been identified. In Fig. 3.12 there are present about 25 unidentified lines, most of them weak. An emission doublet of some interest can be seen at 1243.9 A, 1240.4 A, just to the right of the shorter component of N V in the exposure at +2 sec of arc. This is the transition Mg II 3s $^2S_{\frac{1}{2}}$ - 4p $^2P_{\frac{3}{2}, \frac{1}{2}}$ the first members of the principal series of Mg II. In long exposures on the disk the two lines are present in absorption against the wing of Ly-α; they are the Fraunhofer lines of shortest wavelength as yet obtained in the solar spectrum.

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* G. D. Sandlin, G. E. Brueckner, and R. Tousey, Ap. J. 214, 898, 1977, Forbidden Lines of the Solar Corona and Transition Zone: 975-3000A.

Figure Captions

Fig. 3.1   The optical system of the XUV spectrograph in ATM.

Fig. 3.2   The telescope and the pointing reference servo system
that stabilized the sun's image on the slit; the
long dimension of the slit lies in the plane of the
figure.

Fig. 3.3   Astigmatism of the Rowland mounting.

Fig. 3.4   The pseudoastigmatism of the predisperser ruled with
ten segments of different spacings.

Fig. 3.5   Illumination of the main grating by the ten paneled
predisperser for different wavelengths.

Fig. 3.6   The decrease in length of the spectral lines achieved
by use of the segmented predisperser.

Fig. 3.7   The off-plane aberrations of the double-dispersion
spectrograph and the effect of the segmented predisperser.

Fig. 3.8   The spectral resolution of the ATM spectrograph, showing
points plotted from measurements made prior to flight
and curves calculated with a 3-D ray tracing computer
program. The upper section is for the short wavelength
range and the lower for the long.

Fig. 3.9   The total reflectance of the instrument, including both
main and predisperser gratings and the telescope mirror.

Fig. 3.10 Photographs of two strips of film exposed by SO82B.

Fig. 3.11 The SO82B spectrograph resting on a granite block and
showing the thermal control panels. The camera is
located at the front center of the photograph.

Fig. 3.12 An example of spectra obtained during the limb scan mode.
The wavelength range is 1170-1245 A, about 1/10 of the
entire coverage. Positive limb positions (in sec of arc)
refer to positions above the limb.
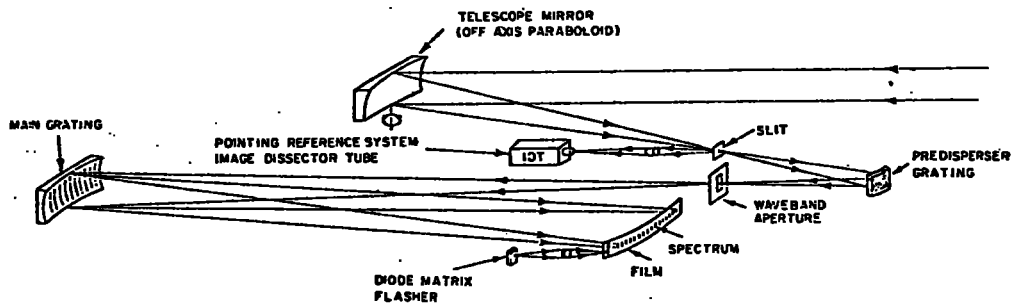
Fig. 1. The optical system of the XUV spectrograph in ATM.
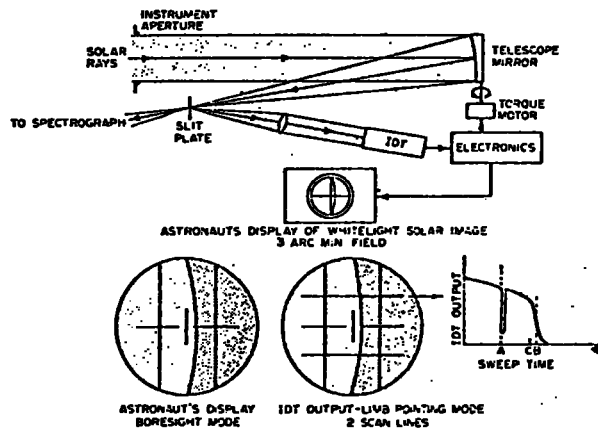
Fig. 2. The telescope and the pointing reference servo system that stabilized the sun's image on the slit; the long dimension of the slit lies in the plane of the figure.
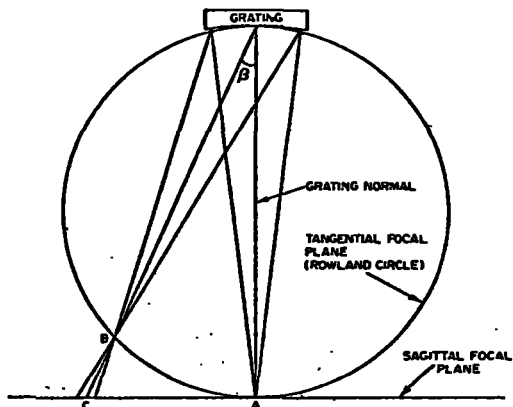
Fig. 3. Astigmatism of the Rowland mounting.
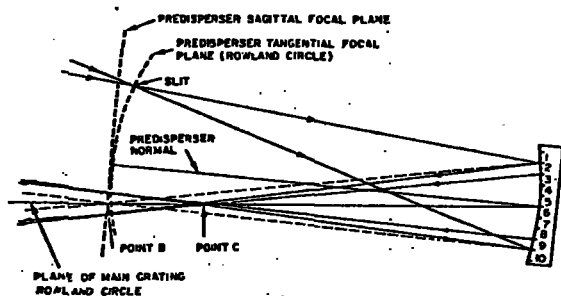
Fig. 4. The pseudoastigmatism of the predisperser ruled with ten segments of different spacings.
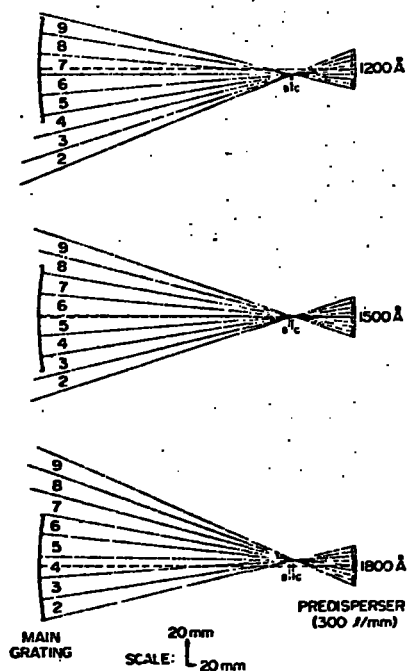

Fig. 5. Illumination of the main grating by the ten paneled predisperser for different wavelengths.
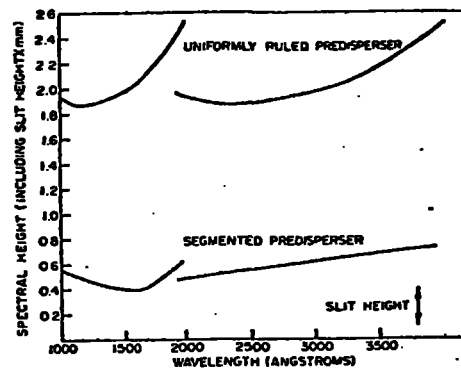

Fig. 6. The decrease in length of the spectral lines achieved by use of the segmented predisperser.
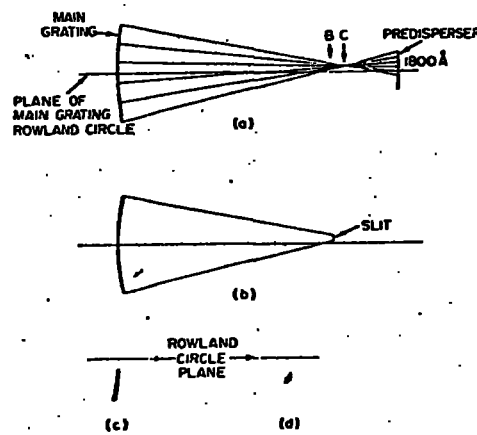

Fig. 7. The off-plane aberrations of the double-dispersion spectrograph and the effect of the segmented predisperser.


Fig. 8. The spectral resolution of the ATM spectrograph, showing points plotted from measurements made prior to flight and curves calculated with a 3-D ray tracing computer program. The upper section is for the short wavelength range and the lower for the long.

COATINGS

TELESCOPE MIRROR	Al + MgF₂
300 //mm PREDISPERSER	Al + MgF₂
150 //mm PREDISPERSER	Al + ZnS + Al + ZnS
600 //mm MAIN GRATING	Al + MgF₂

Fig. 9. The total reflectance of the instrument, including both main and predisperser gratings and the telescope mirror.

FILM CHIP

250 mm

35 mm

SHORT WAVELENGTH END

LONG WAVELENGTH END
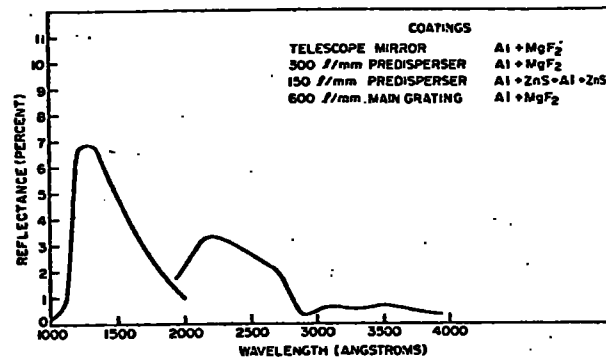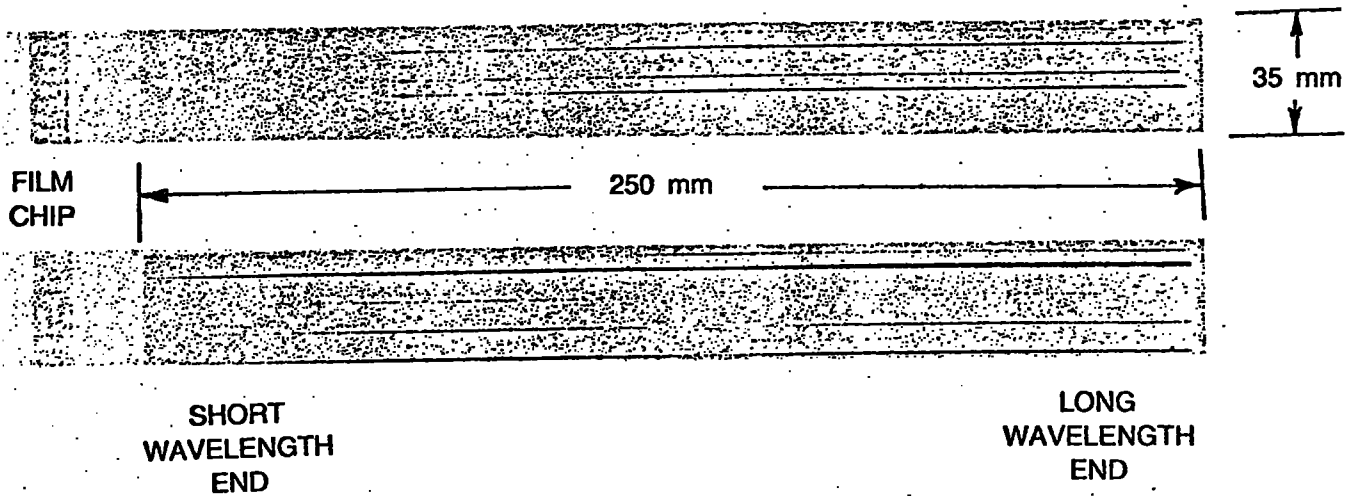
Fig. 10. Photographs of two strips of film exposed by S082B.
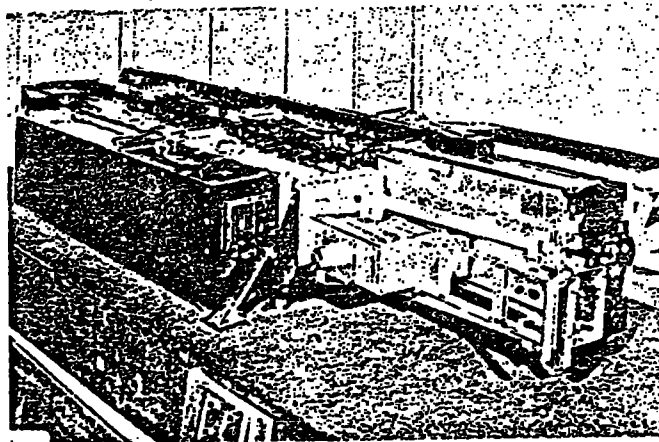

Fig. 11. The S082B spectrograph resting on a granite block and showing the thermal control panels. The camera is located at the front center of the photograph.
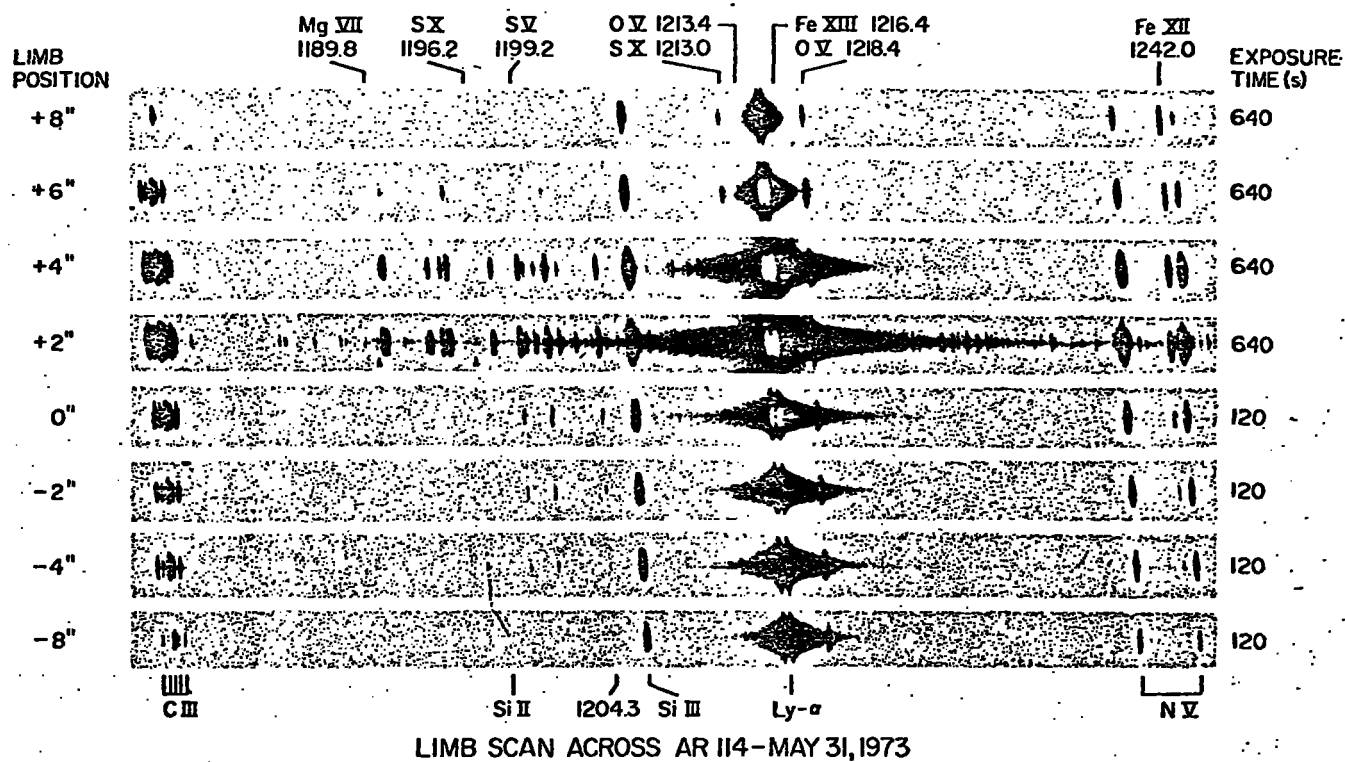
Fig. 12. An example of spectra obtained during the limb scan mode. The wavelength range is 1170–1245 Å, about $\frac{1}{10}$ of the entire coverage. Positive limb positions (in sec of arc) refer to positions above the limb.

4.0 FILM HISTORY*

Commencing in 1946, when V-2 rockets first made possible experimentation from above the earth's atmosphere, there has been an increasing need for photographic film with which to record the XUV spectrum of the sun. The emulsion type most sensitive to the XUV was invented by Schumann in 1892 and perfected by 1901. Schumann recognized the fact that gelatin is opaque to the XUV. As a result he developed an emulsion with just enough gelatin to hold the silverhalide crystal on the base material, but the layer of gelatin was so thin that it was effectively transparent to the XUV. These emulsions could not be touched without destroying them.

For 50 years Schumann plates were made by hand and in severely limited quantities. Eastman Kodak was first to produce a Schumann emulsion on a film base by machine coating. They also developed a method of preventing abrasion between turns of packaged rolls by coating each edge of the film with a spacer 0.2 mm thick, consisting of polystyrene beads held down with gelatin. They named the new, fast emulsion 101 and produced as 104 a slower, but finer-grained emulsion having the beaded spacers. All these emulsions were unprotected, hence extremely susceptible to abrasion. Although now nearly free from defects, fog problems and other effects have continued to arise; some are described in this Guide.

4.1 Batches

The film strips required by the XUV spectroheliograph (SO82A) and spectrograph (SO82B) were 250 mm long and 35 mm wide. To provide for this size, Eastman Kodak produced 104 and 101 films in special rolls, 70 mm in width, and 30 m (100 ft) in length. The required strips were cut from the center. Three rolls were sufficient to provide the 200 strips needed for each camera. Ten rolls were made from one batch of emulsion. Strict controls were required to produce the many batches of emulsion needed to manufacture film that was satisfactory for (ATM) experiments in the large quantity required. In the past it was not uncommon to find variations from batch to batch, and even within a single roll, on the order of a factor of 2 to 5. Eastman Kodak succeeded, however, in improving dramatically the over-all quality of both 104 and 101 films. Large quantities of these films were produced that were uniform to a degree never previously achieved; they were remarkably free from

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*Material for this section has been extracted from a paper in Applied Optics, 16, 887, 1977, by M. E. VanHoosier, J.-D. F. Bartoe, G. E. Brueckner, N. P. Patterson, and R. Tousey. Experience with Schumann-type XUV Film on Skylab. More detailed information about the film may be found in in that source.

blemishes of all kinds. Generally, the sensitivity thres-
hold did not change significantly with batch or from place
to place over a roll. The maximum density D_{max} and the
contrast varied between batches, but not greatly. Type
104 batches having D_{max} between 1.4 and 1.6 (as measured
with a Grant microphotometer) were accepted for use in
ATM.

4.2 Film Sequence Log

Each of 10 cameras exposed for experiments SO82A and
SO82B during Skylab contained film strips cut from several
different rolls, and each camera load of strips was developed
in several different runs. A record was kept of the <u>roll</u>
of film from which each film strip was cut, the <u>emulsion</u>
<u>batch</u> in which that roll was manufactured, and the <u>develop-
ment run</u> in which the film strip was developed. This record
is known as the Film Sequence Log, and it is reproduced
for SO82B in Appendix C. The emulsion batch appears as the
second suffix in the film type number of each roll, i. e.

Film Type

104   —   06   —   05

(Type 104   (7 mil   (batch 5)
   emulsion)   Estar
                 base)

The full complement of film strips (approximately 201)
was exposed in all SO82B cameras. Development run A was
made as a test prior to the full tank runs.

4.3 Mounting

A major design problem in of both SO82 instruments was
the camera. It was decided not to attempt to use Schumann
film in roll form because of the many difficulties associated
with abrasion, environment, static electrical effects, and
precise registration of the film to the focal surface.
Rather, each film strip was carried in its own metal holder,
and approximately 200 strips were held in each camera.

The design of the metal holder involved the choice of
a suitable metal and configuration so that, when bent into
position, the film would lie precisely on the Rowland
circle, within a tolerance of 0.2 mm. An equally important
consideration was to choose a material for the holders that
would not fog Schumann film.

Holders of two types were used for experiments SO82A and SO82B. The first choice was 0.25-mm stainless steel which was believed compatible with Schumann film. It was necessary, however, to increase its stiffness for the 2 m focal plane radius of the SO82A instrument by stamping five depressed ribs lengthwise into each holder; otherwise the unsupported area would not conform properly to the Rowland circle. As discussed in articles about the SO82A experiment, these grooves were found to be a source of fog.

The SO82B focal plane radius was only 1 m, and the tolerance on conformity to the Rowland circle was very tight. For this instrument the holders were made of 0.8-mm thick aluminum sheet, which was sufficiently stiff and uniform so that ribs were not required. However, before forming the retaining lips, it was necessary to reduce by machining the thickness of the aluminum to be bent.

Use of aluminum for film holders had been avoided as long as possible, because of its long history of fogging Schumann film, from rocket experiments and experience in the laboratory. A test program was set up to investigate film fogging by metals. It was found that freshly machined aluminum did, indeed, fog types 104 and 101 films; but aluminum, if completely anodized, did not. Therefore, the aluminum holders were thoroughly anodized after machining and bending. These holders caused no fogging of flight film. Similar precautions were taken with all parts of the camera, even though they were not located close to the film. Black-anodized aluminum, made by dying black the anodized layer before it was dry, was found safe. Magnesium was not used because, when chemically blackened, it produced fog.

Figure 4.2 shows a partially disassembled view of a camera loaded with empty film holders. Each camera, of which 10 were flown on Skylab, was extremely complex. The quasi-carrousel design allowed the loaded film holders to be transferred sequentially and rapidly into and out of the focal position, from one stack of 100 to the other stack, while another transfer occurred at the back. When all the holders had made the circuit once, the camera was fully exposed. In flight, the only camera that malfunctioned was the one actually in place in the SO82A instrument during the launch.

4.4 Processing the Film

Over the years of using Schumann type film, and after considerable additional experimentation, it was decided that D-19 mixed 1:1 with distilled water provides the greatest uniformity, freedom from chemical fog, and minimum Eberhardt, edge and adjacency effects. The following procedure was adopted to provide maximum control and uniform quality of the flight exposures.

One flight strip from each mission was selected and processed alone at the start, to ensure that each returned flight load had not received degradation which could be corrected by different processing. The remainder of the film was developed in batches of 40 flight strips and 10 laboratory - exposed control strips. The flight strips were left in their holders, together with the Plus-X data chip. All strips were attached to a rack in a vertical position. The solutions were held in large, stainless steel tanks. Each tank contained 40 liters of solution, a quantity considered sufficient to process the entire contents of one camera without depletion.

The rack of 50 film strips was first presoaked in a tank of distilled water for 4 minutes. This was an important step because it prevented infectious development by allowing the dried-out gelatin pad to swell. Otherwise, whiskers growing on exposed grains could touch adjacent unexposed grains, making them developable. Immersion in the water was done quickly, but smoothly; if strips are immersed unevenly, marks are produced by the stresses of nonuniform swelling. All solutions were maintained at 20° C. It was important to avoid elevated or changing temperatures, which would cause reticulation of the gelatin pad. Development was for 4 min., followed by 30 sec in acetic acid short-stop, 4 min. in Kodak acid fixer, a 20 min. wash in filtered tap water, removal to a class 10 K clean room, rinsing in distilled water, and hanging to dry.

An important part of the development process was the use of N_2 bubble agitation, introduced through an array of many small holes, roughly 3/4" apart, in a plenum at the bottom of the tank. A one second burst of N_2 was produced at 10 sec intervals. In addition, the entire film rack was moved laterally by hand, alternately parallel and perpendicular to the film, at a speed of about 1 cm per sec. This procedure had been found to produce uniform development.

The five development runs which were required for each camera could be completed in one day. The development process was controlled by including in each development the 10 control strips of film from the same batch on which

a standard series of exposures had been placed 48 hours
earlier. These 2 cm by 10 cm strips were exposed to the
continuum spectrum of a D_2 lamp, dispersed by a McPherson
normal-incidence monochromater/spectrograph. The exposure
times were 1 and 10 sec. The intensity was reduced in
steps of a factor of 2 by means of sectored disks, covering
the range of 1:100 in transmittance. The spectral range
was 1650 to 2400 A. Use of these control strips was mainly
to serve as a check that the development was the same each
time it was carried out. The H - D curves of control strips
developed in various runs were found to agree to $\pm$ 0.02
in log E.

Finally, the dry film strips, while still in the clean
room, were mounted between high quality glass plates of 1.25
mm thickness, which had been anti-reflection coated on the
inside surfaces to minimize Newton's rings. The film strip
was surrounded with a brass spacer, of thickness slightly
greater than the film. This, together with the normal curl,
prevented the emulsion from being touched by the glass.
The sandwich was then sealed with plastic tape and stored
in a vault.

4.5   Loss of D_{max} and Contrast

An unexpected film effect was a reduction in D_{max} and
contrast on all of the flight film, apparently due to pro-
longed exposure to the hard vacuum in space. Figure 4.2
shows a comparison between the characteristic curves for
Types 101 and 104 flight film and those for film samples
from the same emulsion batch kept at 2^0 C in the laboratory.
Especially conspicuous is the long, flat maximum on the
flight film. This is followed by a sudden turn-down caused
by solarization, for extremely high exposures (typical of
solar flares). These curves show that there was no loss in
threshold sensitivity. Film stored for an extended period
under vacuum in the laboratory did not show this effect.
That the loss was due to a cause other than degradation of
the latent image was shown by sensitometric tests made post-
flight on unexposed strips of flight film.

4.6   Fog

Fog levels expected from the proton flux did not
materialize in flight. It had been realized that the fog
prediction was not too certain, therefore a single strip
of type 101 film was included as a test in most cameras
on SL-2 and 3. The proton fog level for type 104 film
was negligible and for type 101 only 0.02. The explanation
appears to be that the proton flux from the South Atlantic
anomaly was much less than was expected, and also that
the shielding provided by the Skylab was more effective
than calculated. Furthermore, high temperatures were never

experienced. No fogging of the film occurred due to ions,
metallic surfaces, or contamination.

There was insufficient time to include any type 101
film in cameras resupplied in SL-3. However, some was
included in the cameras for SL-4. The five times greater
sensitivity made possible several investigations. It
permitted recording coronal spectra to greater altitudes
above limb than was possible with type 104. Through its use
the profile of hydrogen Lyα as emitted from the extended
hydrogen cloud surrounding the comet Kohoutek was photo-
graphed, and it extended to shorter wavelengths the spectral
coverage of SO82B. This successful use of type 101 was,
however, at the expense of added risk of fogging, reduced
accuracy of calibration, and increased granularity.

Figure Captions

Fig. 4.1　A photograph of a loaded and partially disassembled camera. Only the upper stack of 100 film holders can be seen. The closed shutter is seen in the plate at the right. All the actuator mechanisms were located at the sides.

Fig. 4.2　Typical curves of density vs log exposure for Eastman Kodak types 101 and 104 film. One set applies to film that had been exposed to the space vacuum during Skylab, while the other is for control film kept at 2°C in the laboratory. The extension of the type 104 curve to large values of exposure shows the solarization response, as estimated.
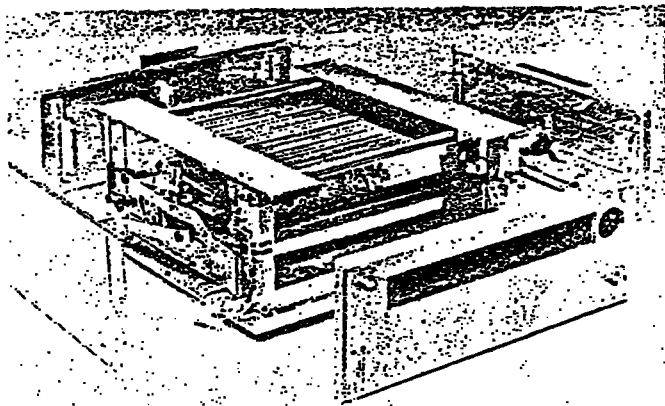
Fig. 4.1 A photograph of a loaded and partially disassembled S032A camera. Only the upper stack of 100 film holders can be seen. The closed shutter is seen in the plate at the right. All the actuator mechanisms were located at the sides.

Fig. 4.2 Typical curves of density vs log exposure for Eastman Kodak types 101 and 104 film. One set applies to film that had been exposed to the space vacuum during Skylab, while the other is for control film kept at 2°C in the laboratory. The extension of the type 104 curve to large values of exposure shows the solarization response, as estimated.

5.0 CALIBRATION AND ABSOLUTE SPECTROPHOTOMETRY*

Accuracy of calibration of instrumentation used in the extreme ultraviolet has always been a problem of great difficulty. Early in the ATM program it was proposed by HCO and by NRL that their instruments be calibrated by comparison with carefully standardized instrumentation flown in rockets. One calibration rocket (CALROC) flight per mission for each institution was considered to be the minimum required because the sensitivity of the ATM instruments was expected to change during the course of the nine months over which they would be used. The fundamental idea was to make simultaneous solar measurements using both rocket-borne and ATM instruments. Absolute intensities derived from the well-calibrated rocket instruments would then serve to calibrate the sun so that it could serve as a standard source with which to calibrate the ATM instruments.

The plan of NRL was to fly instruments almost exactly like those of ATM but reduced in size by a factor of two. The ATM spectrograph could operate in either of two wavelength ranges: 970-1940A, or 1940-3940A. In the latter, or "long wavelength" range, absolute intensities had already been well-determined by Tousey et al. (1) and by Broadfoot (2). Therefore the CALROC instrument could be simplified and improved over the ATM instrument by eliminating the long wavelength range and utilizing both the main and predisperser gratings in the first order. In this manner stray light which was present in the ATM instrument was eliminated from the CALROC instrument.

NRL, together with Ball Brothers Research Corporation (BBRC), Goddard Space Flight Center (GSFC), and the Ames Research Center, developed a command system by which the instrumentation section of the rocket, after separation from the booster, could be pointed at particular positions on the sun. This was done by a radio command link combined with a television system which displayed to the PI on the ground an H-α image of the sun reflected from the slit plate of the spectrograph. By command loop the PI could then orient the slit precisely during the flight to any desired solar feature.

The CALROC program required a great effort, but the results proved to be highly successful. In the remaining

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* Material for this Section has been gathered from helpful discussions with Drs. K. R. Nicolas, O. Kjeldseth Moe, N. P. Patterson, J. W. Cook, G. A. Doschek, and U. Feldman. Portions of material have been extracted from References 3, 5, 6, 7, and 8, listed at the end of this Section.

paragraphs of this Section, methods of obtaining absolute solar intensities from the ATM data are discussed. First the CALROC instrument and the method used for its absolute calibration in the laboratory are described. Reduction of the CALROC solar exposures then gave absolute solar intensities, which were published in a spectral atlas for the range 1175 to 2100A (3). By comparison of identical spectral features measured by CALROC and ATM, a wavelength-dependent absolute sensitivity plot was produced for the ATM spectrograph during the second Skylab mission. A method which can be used to transfer this calibration to other film batches and other Skylab missions is then presented. Also included is a discussion of precautions to be observed in the photometry of the ATM film. Finally, the method and instrumental response curve needed to obtain absolute intensities from the long wavelength ATM data are provided.

5.1 CALROC Calibration

CALROC flights were made on June 13, 1973, Sept. 4, 1973 and Jan. 15, 1974. The calibration instrument, flown on a Black Brant VC rocket, was a 1/2 scale model of the ATM SO82B spectrograph and used a 1 m focal length off-axis parabolic mirror to focus a solar image onto the spectrograph slit. Behind the entrance slit was a double dispersion spectrograph. A predisperser grating, consisting of panels with slightly varying grating constant (average 200 lines mm^{-1}), formed a dispersed image of the slit on a slot which selected the wavelength band to be recorded and blocked all visible light from striking the main grating (2150 lines mm^{-1}), which was mounted in a Rowland configuration. Both gratings were used in the first order; this eliminated stray light which was present in the ATM instrument. (See Sec. 3.3). The film strips on the Rowland circle were 200 mm long and covered the spectrum from 1170 to 2100 A with a dispersion of 4.7 A mm and a spectral resolution of 0.07A, closely comparable to the ATM spectrograph (See Sec. 3).

An absolute calibration of the CALROC spectrograph was made in the laboratory utilizing a standard deuterium (D$_2$) lamp calibrated as a function of wavelength between 1650A and 2600 A at the National Bureau of Standards (NBS) before and after the flights. For shorter wavelengths this source cannot be used as a standard because of the appearance of numerous D$_2$ molecular lines. Between 1250 A and 1700 A a relative spectral calibration was obtained after the flight using a high pressure argon arc as an intensity standard (Bridges and Ott, (4)). By matching this relative calibration from the argon arc to the deuterium lamp absolute calibration above 1700 A, it was then possible to extend the absolute calibration of the rocket instrument to 1250 A. A detailed description of the deuterium lamp calibration is given by Brueckner et al. (5), while Kjeldseth Moe et al. (3) have described the argon arc calibration.

Spectra of the deuterium lamp were exposed by the instrument before and after each flight to detect any change in instrument sensitivity. In addition, segments of the lamp spectrum were placed on each strip of the flight film prior to flight to minimize errors resulting from film inhomogeneities, development problems, and film environment during flight. These segments were exposed with the flight instrument, using a 1 m off-axis parabola as a collimator. Short of in-flight calibration, this method was as close as possible to an ideal calibration for irradiance measurements. The only optical element which had to be measured independently was the collimator mirror. Care was taken to assure that the illumination of all optical elements of the flight instrument was identical during the calibration and the solar exposures.

The film characteristic curves relating film density above fog level to relative exposure were constructed from a series of flight exposures in the manner described in Sec. 5.3.1. Fig. 5.1 gives an example of the CALROC characteristic curve.

Absolute solar intensities derived from the CALROC program for use in the ATM calibration have been published as "A Spectral Atlas of the Sun between 1175 and 2100 A" (3), described in more detail in Sec. 8. The data have also been used in various other studies of the sun, which are listed in the Bibliography, Appendix D.

5.2 ATM Calibration

CALROC essentially calibrated the sun, making it a secondary standard source. As nearly as possible the CALROC instrument observed the same regions as the ATM, although at a time which was a few hours away from the ATM observations. The accuracy attained in pointing both instruments, together with the closeness in times of observation, made the calibration of the ATM intensities from CALROC both simple and accurate. Only a direct transfer of intensities from the CALROC spectra to the ATM spectra was involved, without the need to consider the possibility of changes in instrument or film sensitivity.

The instrument sensitivity curve derived from a comparison of ATM and CALROC exposures is presented in Fig. 5.2. (Kjeldseth Moe and Nicolas (6) and Nicolas (7)). The logarithm of exposure, E, (=It) is plotted vs. wavelength. Absolute units on the ordinate scale are given in terms of the intensity, I, of the source in ergs $cm^{-2}s^{-1}sr^{-1}A^{-1}$ required to produce an exposure of density 0.30 in 1 sec. Above 1500A the curve was derived from measurements of the continuum and also of emission lines from neutral and singly ionized atoms.

Below 1500 A, only lines from neutral and singly ionized species were used (7).

In addition, the calibration curve has been modified to incorporate more accurate data obtained from a reflight of the CALROC instrument on Oct. 22, 1976. At that time, the argon arc had become available as a calibration source, and measurements of the arc intensity were made close to the date of flight, both before and after launch.

For photometry on the linear part of the film characteristic curve, as described in Sec. 5.3.1, the estimated accuracy of intensity measurements derived from the data of Fig. 5.2 is 50% rms. The uncertainties in the film characteristic curve, in the original deuterium lamp calibration, in the relative calibration with the argon arc, and in the transfer of the rocket calibration to the ATM instrument all contribute to the total error.

An independent calibration of the short wavelength ATM data has been published by Doschek, Feldman, VanHoosier, and Bartoe (8). They compared arbitrary continuum intensities obtained from the Skylab spectra with the absolute intensities at sun center in the quiet sun continuum published by Samain et al. (9). From the comparison they derived conversion factors to place their line intensities on an absolute scale. Their intensities thus converted to absolute values agree well with the spectral intensities derived from Fig. 5.2 between 1400A and 1700A. Above 1700A the values agree to within a factor of 2, with Doschek et al. high by a factor of about 1.8 at 1900A.

Below 1400A, where the ATM continuum became too weak to measure, Doschek et al. made use of the reflectivity curve for the SO82B instrument (10) for their determination of conversion factors. Absolute values for their intensities in this spectral range lie below the CALROC calibration by at most a factor of 2.

5.3 Photometry of SO82B Spectra

All intensity measurements of the SO82B data of NRL have been derived from specular density measurements of the film made with a Grant microdensitometer, operated under control of a PDP-8 minicomputer. Various members of the staff have developed individual methods and computer programs for reducing the data. Investigators analysing the spectra may wish to make collaborative arrangements to utilize this expertise.

5.3.1 Characteristic Curves

The film characteristic curves must be constructed from the flight exposures. The method consists of comparing film densities above fog level at exactly the same wavelengths on exposures taken with different exposure times but at the same pointing. Spectral features are selected to cover a wide range of intensities. Thus many sets of film densities vs. exposure are obtained. The curve of density vs. log exposure (log E) is synthesized by sliding the many sets of points independently along the log E axis until a best fit to an average curve is obtained. The method assumes that a possible reciprocity failure is small and can be disregarded. The assumption is valid in general for exposure times within a factor of 10 of one another. Exposures farther apart must be investigated on an individual basis. The curve should be normalized to a standard position of log E = 0.00 at D = 0.30 for a 1 sec exposure in order to make direct use of the absolute calibration data of Fig. 5.2, as described in Sec. 5.3.2 below.

Figure 5.3 shows two representative H&D curves developed in the above manner for the wavelength regions shorter and longer than 1400 A. It was found from examination of small wavelength intervals throughout the spectral range that for these particular exposures, from one film batch and development run, there was a continuous transition in the slope of the quasilinear part of the characteristic cruve with increasing wavelength. Other film batch and development runs have not always shown this.

In deriving the ATM characteristic curves, attention must be paid to the film batch number and development run. For this purpose the "Film Sequence Log" given in Appendix C lists each film strip or "plate," and the batch number of the film roll from which the strip was cut. Also included is the development run in which the film was developed. The characteristic curves may vary with each of these parameters. (See Sec. 4 for a discussion of the ATM film). For one batch and development run it is often possible to cover the range 1175-1960 A with two curves, for wavelengths above and below 1400 A, respectively. The shape of these characteristic curves is similar for a number of batch number and development runs, but can differ and should be examined. There is no "standard" characteristic curve.

Scatter of the data points about the final curves obtained using the above method varies considerably, depending to some extent on the spectral width of the band from which the points are selected. There is usually increased scatter at film densities below about 0.05 above fog level, the toe region of the curve, and also in the shoulder of the curve. Photometry in these ranges should be avoided, if at all possible.

5.3.2 Conversion to Absolute Intensity

The absolute intensity, I_{Abs}, for any exposure E, (=It), at any wavelength, λ, is found from the relationship

$$\log I_{Abs} (\lambda) = \log E_{Abs} (\lambda) - \log t + \Delta\log E_{rel}. \quad (5.1)$$

Log E_{Abs} values are read from Fig. 5.2. Several of the values which make a convenient table for computer use have also been listed in Table 5.1. Delta log E_{rel} is the log exposure correction required to take into account the actual measured density of the particular feature. It is read directly from the H-D curve which is normalized for log E = 0.0 at D = 0.3. Exposure time is t.

To illustrate the method, Table 5.3 lists values for the long wavelength relative characteristic curve of Fig. 5.3. A film density of 0.4 at 1500 A on an exposure of 10 sec would give an absolute intensity whose log is 4.891-1.000+0.238. The absolute intensity is then 1.35×10^4 ergs cm^{-2} s^{-1} sr^{-1} A^{-1}.

5.4 Slew Calibrations and Variations in the ATM Sensitivity Curve

Special calibration exposures under conditions as nearly identical as possible were programed during the Skylab missions to aid in evaluating the several instrumental parameters which were susceptible to variation with time. These include the absolute sensitivity of the film and the reflectivities of the optical surfaces. The exposures were programed every several days and were made with the ATM spectrograph pointed to a quiet region 300" inside the solar limb (μ =0.73). The instrument was slewed back and forth in a direction perpendicular to the slit length to average out fluctuations along the slit and thereby covered a quiet solar area of one square arc min. on a regular basis. Throughout the mission other exposures useful as checks on the absolute calibration were made at quiet region pointings 12" and 25" inside the limb, where instrumental stray light was low.

A listing of the slew exposures is given in Table 5.2, which is organized by film groups. Plates from a common film batch, roll, and development are listed together opposite columns containing the identification numbers of those parameters. Serial numbers of the plates containing slew exposures and the day of year date of the exposures are given opposite the group of plates within which they are found. A more detailed listing, which includes exposure frame and exposure time, is available among the Skylab documents at NRL.

C. Y. Yang, N. P. Patterson, and O. Kjeldseth Moe have
made a thorough study of the slew exposures on 104 film
(11). They found that the most consistent information was
obtained from densitometer scans of continuum areas between
1914 and 1956A, which were almost completely free of scatter-
ed light. Scans of emission lines were difficult to evaluate
because of variations in the amount of network cells or bound-
ary areas included in the slewed region. Other difficulties
encountered with the slew exposures involved the manual con-
trol of the exposures, with errors up to $\pm$ 1/4 sec. at the
beginning and end of an exposure. A "worst case" error was
observed for 2 exposures taken on the same day by the same
astronaut, differing in relative exposure by 44%. Three days
later the same conditions registered a relative exposure
difference of only 20%. A plot including the slew measure-
ments from all missions shows that variations in exposure
were within $\pm$ 25%, and that no significant degradation of the
instrument or optics could be detected.

From Table 5.2 it may be noted that each of the cameras
used with the SO82B instrument contained film from only one
batch, and that each camera contained a different batch. Al-
though no differences in the slew calibrations were noted
which might correlate to batch, roll, or development run,
several investigators have noticed variations in D_{max} and
contrast when H-D curves have been plotted. It is therefore
recommended that the absolute value of the sensitivity curve
of Fig. 5.2 be checked at one or more wavelengths.

The absolute sensitivity curve can be checked by
comparing absolute intensities derived from selected regions
of slewed spectra closest to the spectra being interpreted
with values contained in the CALROC spectral atlas published
by Kjeldseth Moe et al. (3). From the comparison, a cor-
rection factor for Fig. 5.2 at one or more wavelengths
can be obtained. Assuming that film sensitivity remains
uniform with wavelength throughout the Skylab missions, the
entire curve for Fig. 5.2 can then be shifted to match the
corrected points. The best spectral regions to use for the
comparison measurements lie above 1850A or below 1500A, where
where the first order stray light is minimum. (See Sec. 3.3
for a discussion of the stray light.) Above 1950A there is a
mixture of continuum, absorption and emission features, while
below 1500A, only emission lines are available. Although in
principle only one region needs to be checked, it is useful
to compare several in order to obtain an estimate of the
error in calibration.

5.5 Curvature of Spectra

Both the ATM and the CALROC spectra are bowed along the
dispersion, the ends of each spectrum line deviating several
hundred micrometers from a tangent to the middle position.
To ensure that the photometer slit always stays in the region
of uniform exposure, densitometry of the spectra must be

performed in segments, or a computer program may be devised to
control the scan automatically, the exact procedure depending
upon the user's project.

5.6 Long Wavelength Calibration

No direct intensity calibration of the long wavelength
range of the spectrograph was made. It was considered un-
necessary, because the intensity distribution in the solar
spectrum from 2000 to 3000A, approximately, is well known and
is believed not to vary significantly with changing solar con-
ditions.

The steps required to convert film density measured from
a long wavelength spectrum to absolute units have been des-
cribed by Doschek, Feldman, and Cohen (12). The conversion
begins with the establishment of a characteristic curve for
the film batch of interest, as described in Sec. 5.3.1 above.
Relative intensities derived from the characteristic curve are
then converted to absolute intensities by reference to one of
several published solar atlases covering the spectral region,
such as Tousey, et al. (1) 1974, or Broadfoot (2) 1972.

The major difficulty encountered in obtaining absolute
values for the ATM data involves selecting the proper cor-
rection for limb darkening in order to relate to the values
tabulated in the atlases, which apply to the radiation from
the total sun. Doschek et al. made use of the value from
Allen (13) for 2800A based on work by Bonnet (14). Depend-
ing upon the individual research problem, each investigator
will undoubtedly select his own approach to this correction.
The limb darkening function is by no means independent of
wavelength in the UV. A forthcoming publication by Kjeldseth
Moe and Milone (15) lists coefficients for limb darkening
equations, derived as functions of from the ATM data.

5.5 References

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Figure Captions

Fig. 5.1   Example of film characteristic curve determined
            from the CALROC exposures. Crosses mark the
            observed points shifted along the exposure axis
            to form the best possible average curve, Kjeldseth
            Moe et al. (3).

Fig. 5.2   Absolute calibration curve for ATM 104-type film.
            Prepared by Kjeldseth Moe and Nicolas (6) and (7).

Fig. 5.3   Example of relative characteristic curves for one
            film batch and development run on ATM 104-type
            film.

Fig. 5.3 (a) Wavelengths shorter than 1400 A.

Fig. 5.3 (b) Wavelengths longer than 1400 A.
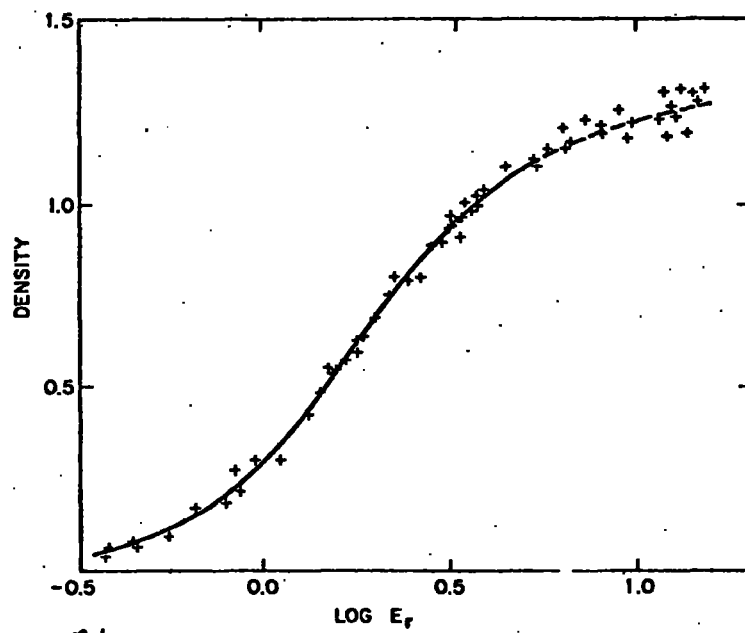
Fig. 3 — Example of film characteristic curve determined from the flight exposures. Crosses mark the observed points shifted along the exposure axis to form the best possible average curve.

Fig. 5.2

WAVELENGTHS SHORTER THAN 1400Å

a

WAVELENGTHS AT 1400Å AND LONGER

b
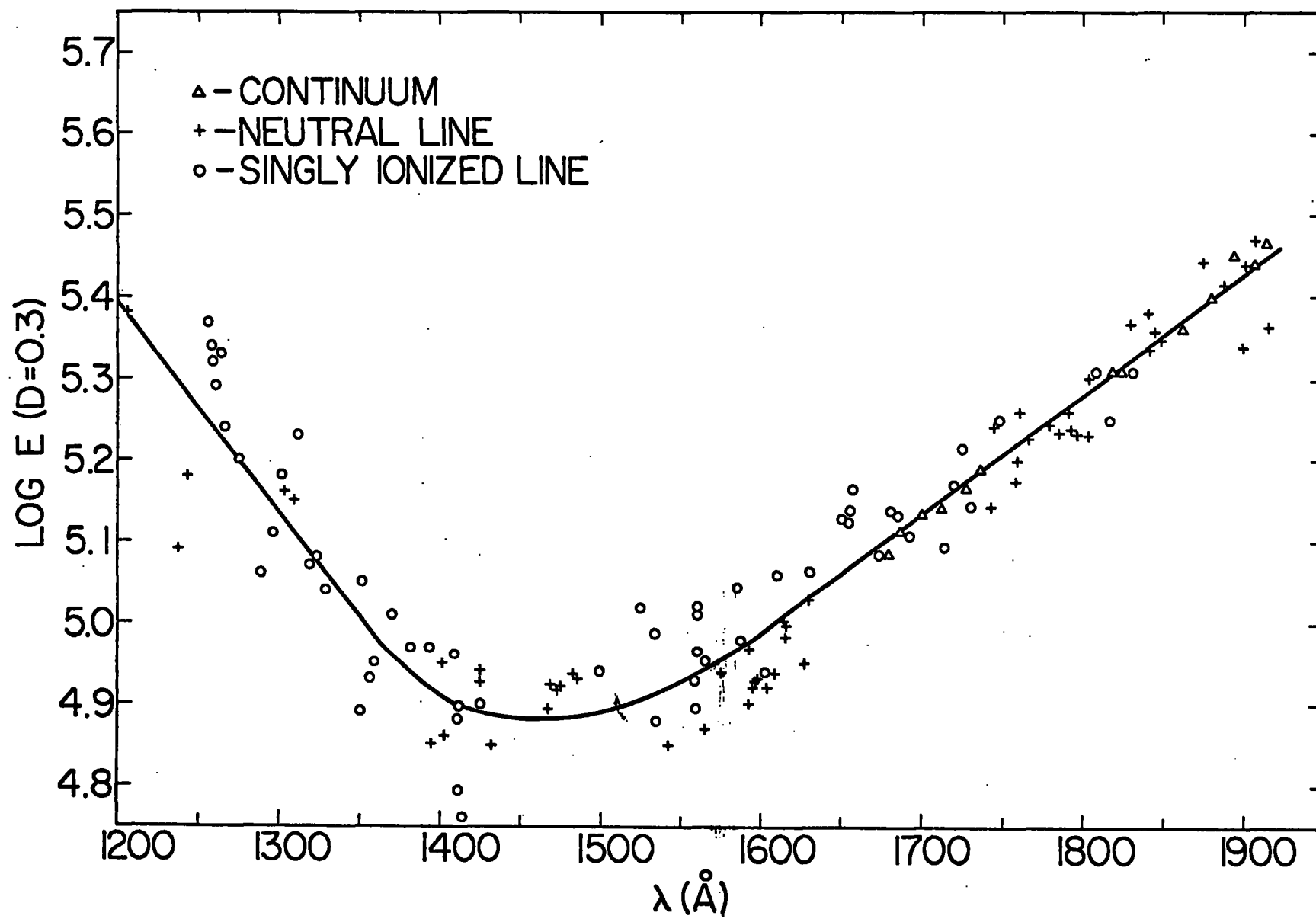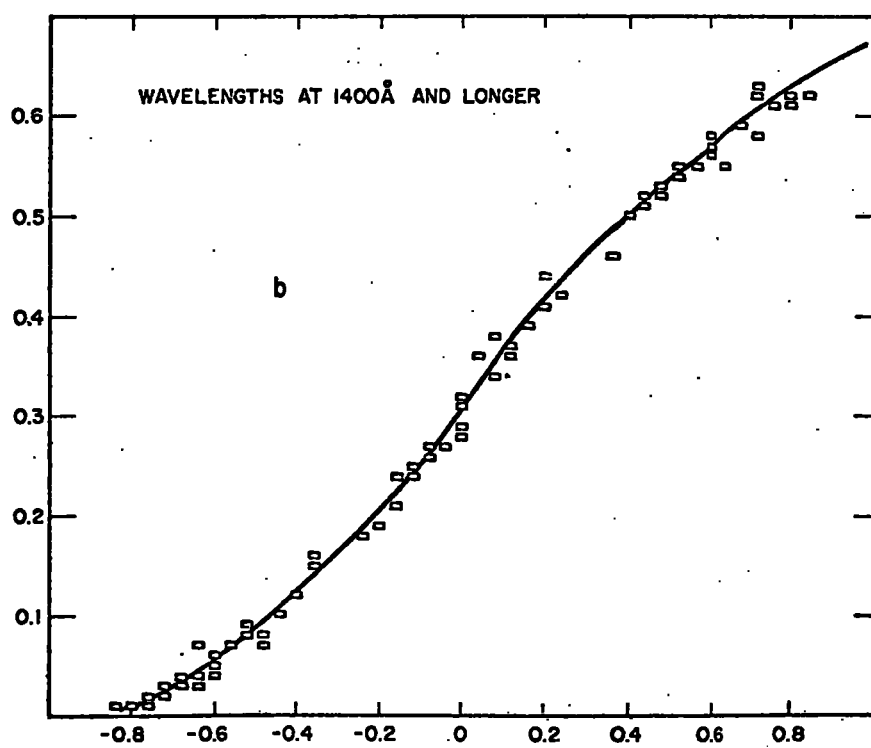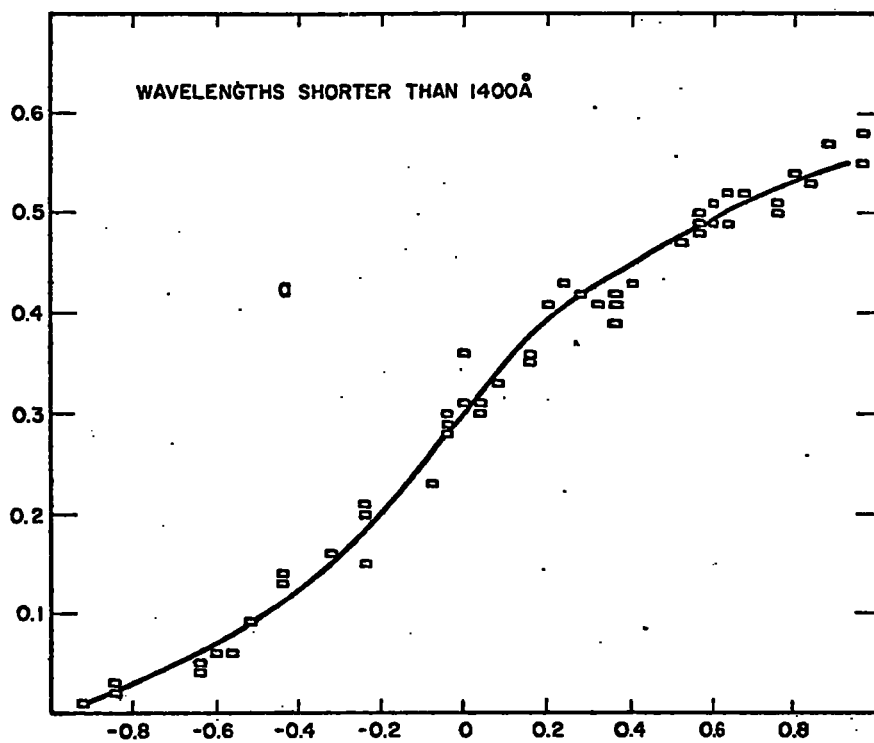
Fig 5.3

Table 5.1 Absolute Calibration of SO82B Instrument (104 film)

Wavelength	Log E_{Abs} (D=0.3)
1160.0	5.497
1200.0	5.394
1206.0	5.379
1400.0	4.883
1450.0	4.884
1500.0	4.891
1514.0	4.900
1535.0	4.915
1557.5	4.935
1577.0	4.958
1600.0	4.989
1900.0	5.425
1960.0	5.512

Table 5.2 Data from Fig. 5.3 Characteristic Curve

Density	Δ Log E_{rel} (λ)
0.000	0.954
0.020	0.835
0.040	0.729
0.060	0.633
0.080	0.548
0.100	0.472
0.150	0.316
0.200	0.196
0.250	0.095
0.300	0.000
0.350	0.106
0.400	0.238
0.450	0.412
0.500	0.643
0.520	0.755
0.540	0.879
0.560	1.017
0.580	1.170
0.600	1.338

Table 5.2 SO82B Slew Exposures and Film History

Mission	Plate No.	DOY	Slew Plate No.		Batch	Roll	DevRun
SL-2	1B001				04	6A	3
Camera B1	1B002				04	3	1
	1B003-1B018	150	1B011		04	7B	1
	1B019-1B041	153	1B035		04	8A	1
	1B042-1B078	153	1B061/2		04	8A	2
		157/158	1B075				
	1B079-1B081				04	7B	2
	1B082-1B103	161	1B083		04	7B	3
	1B104-1B107	162	1B106		04	7B	5
	1B108-1B142				04	7A	5
	1B143-1B177	164	1B145/6	CALROC I	04	7A	4
	1B178-1B182				04	7B	4
	1B183-1B201	167	1B192		04	7B	3
		168	1B194				
SL-3	2B001				06	3	1
Camera B2	2B002				06	2	A
	2B003-2B021	220	2B014		06	2	1
	2B022-2B040				06	1	1
	2B041-2B080	225	2B057/8		06		
		225	2B064/5			1	2
	2B081-2B091				06	1	3
	2B092-2B103				06	2	3
	2B104-2B144	229	2B140		06	2	5
	2B145-2B150				06	2	4
	2B151				05(101)	3(101)	4
	2B152-2B184	231	2B171		06	3	4
		231	2B175				
	2B185-2B192				06	3	3
	2B193-2B201	233	2B194		06	2	3
		234	2B198/9				
		235	2B200				

Table 5.2 (Cont.) SO82B   Slew Exposures and Film History

Mission	Plate No.	DOY	Slew Plate No.		Batch	Roll	DevRun
SL-3	2B301-2B303	237	2B303		06	3	1
Camera B3	2B304	237	2B304		05(101)	3(101)	1
	2B305-2B339	238	2B332/3		05	17	1
	2B340-2B341				05	17	2
	2B342-2B376	241	2B355/6/7		05	18	2
	2B377-2B380				05	17	2
	2B381-2B401	244	2B387		05	17	3
		244	2B391/2				
	2B402				05	17	5
	2B403-2B439	247	2B418/19	CALROC II	05	16	05
		247	2B426/7				
	2B440-2B479	249	2B446		05	16	4
		251	2B465				
		254	2B477				
	2B480-2B499	255	2B480/1		05	17	3
		257	2B483				
		258	2B488				
		260	2B492				
		262	2B498				
	2B500				05	17	A
	2B501				05	17	1
SL-4	3B001-3B017	333	3B004		08	8	4
Camera B4	3B018-3B036	340	3B026/7		08	8	3
	3B037-3B047				08	8	1
	3B048-3B077				08	9	1
	3B078-3B100				08	9	2
	3B101-3B108				08	9	4
	3B109-3B123				10(101)	4	
	3B124-3B158	007	3B156/7		10(101)	4	5
	3B159-3B164	011	3B159/60		08	8	5
	3B165				08	8	1
	3B166-3B184	016	3B175	CALROC III	08	8	3
	3B185-3B201	030	3B200/01		08	8	2

The SO82B flight film is kept in a secure area at the Naval Research Laboratory, Washington, D. C. Anyone who needs to perform an analysis from the original film should contact Dr. Richard Tousey, Code 7140, Principal Investigator, or Mr. Richard Schumacher, Code 7149, Program Manager.

Individual flight film strips are 35 x 250 mm in size and have been mounted for protection between 2 x 12 inch glass plates separated by thin brass spacers. Now referred to as "plates", all original material, consisting of 6408 spectra, has been copied at 1.8-times magnification onto 70-mm Kodak 2421 Aerial Duplicating roll film (Estar Base) and archived at the National Space Science Data Center (NSSDC). A 21-step wedge was also enlarged and photographed with the plates to enable the generation of transfer curves from flight film to users' copies. Members of the scientific community may obtain high quality fourth-generation positives and fifth-generation negatives from NSSDC (the flight film is considered first generation). Also available with these data are film catalogs on magnetic tape or microfiche and the "NRL/ATM User's Guide to Experiment SO82B."

Figure 6.1 illustrates the photographic history of copies available for distribution to interested users. The master positive copy, produced at NRL, was used to make a contact working negative at NSSDC, and a working positive was then printed from the first working negative. Users' copies, as indicated, are then produced from the working copies. During the entire photographic procedure, care was taken to produce a high quality uniform product, and good quality control is exercised at NSSDC in the film processing. With multiple generation copies, however, there is some loss of fine detail in the fainter spectral exposures. It is expected that the copies will be useful primarily as intermediate negatives or positives from which prints can be made, or they can be used in various qualitative or survey-type investigations.

6.1 Photographic Procedures

In the duplication of the flight exposures it was found necessary to develop photographic equipment for the purpose. This equipment, the duplicating film, and the processing were selected to obtain optimum resolution, moderate grain compression on the copy film, and to retain the full density range of the data. In the enlarger, a 600W quartz lamp was used to obtain maximum resolution, acutance, and image contrast. This point light source was adjusted in position to minimize color fringing and parallax and to achieve best uniformity of illumination. The uniformity attained was found to be within ±6% over the entire film plane. The lens was selected to minimize distortions and curvature of field.

Alignment of the system was achieved with a helium-neon autocollimating laser, using three-point control at the lens board and at the carrier for the film magazine. A vacuum back was used to hold the film flat at the enlarging surface.

The film was stored at 55° F until 24 hours prior to use and was refrigerated after exposure until time to be processed. These precautions were taken to minimize latent image loss and fogging of the film.

The plates were copied in small groups. At the beginning and end of each photographic session, the film was given a sensitometric exposure using a Kodak Process Control Sensitometer, Model 101. These frames reside on the film at NSSDC, and were used primarily to check the uniformity of film development from beginning to end of a particular group. A great amount of credit is due NSSDC in maintaining its processor control to such a degree that no significant differences could be measured from end to end in the various development runs.

The processor was a Kodak Model 11 Versamat with one rack, employing Hunt E. R. Aeroflo (Regular) developer at 85° F. The film was of one batch number and was processed to a gamma of 1.0. Sensitometric strips at NSSDC developed at intervals during the runs verified the gamma to a tolerance of about 0.02 as derived from measurements with a Macbeth Model TR524 densitometer (diffuse density).

6.2 Transfer Curves

Of more importance to a user who would attempt rough photometric use of the film is the 21 step Kodak calibrated wedge which was photographed with the copy camera at least once during each copy session at NRL. The film in the wedge conforms closely to the dimensions and granularity of the flight film and was mounted identically between glass plates of the same size and thickness as the S082B mounting plates. Table 6.1 is a listing of the various exposures, giving the location of a particular wedge whose exposure and general history matches a group of flight frames. The symbols in front of the plate numbers indicate a wedge image just prior to or just after that plate. For example, a wedge exposed and processed with plate number 2B148 will be found just before plate 2B146 and another just before plate 2B151 on the roll film. Although the wedge in front of 2B161 was processed at the same time, it was exposed nearer in time to plates 2B161 through 2B201, indicated by a semicolon dividing the groups in the table. Frequent use was made of the step wedge to insure evaluation of possible latent image loss or changes caused by differences in the development process which might occur from one group of exposures to another. In either case a transfer curve can be plotted

for any particular group of exposures by plotting step
densities of the wedge listed in Table 6.2 against wedge
densities measured from the users' copy.

Typical transfer curves derived from the wedge images
are shown in Figs. 6.2 and 6.3. Figure 6.2 characterizes
the master positive film archived at NSSDC. Diffuse
densities of the copy were measured on a Macbeth Model TD
100A densitometer and are plotted against the Table 6.2
specular densities of the wedge itself, obtained with the
the NRL precision Grant microdensitometer. Both specular
and diffuse step densities of the wedge are given in Table
6.2. Specular density was used in this case in order to
relate to the various phenomena measured on the flight film
by members of the NRL data analysis team. Since most data
of value fall between about 0.10 and 1.00 specular density
units on the flight film, the copy data were deemed useful
when the transfer curve was straight in that density range.
As shown in Fig. 6.3, a good curve was also maintained
for the user's generations of film, with D_{max} (diffuse) of
about 1.8 for the Users' Positive and about 2.0 for the
User's Negative. D_{min} values for the Positives and
Negatives are 0.22 and 0.35 respectively.

6.3 Image Degradation

Mounted between glass plates holding the Kodak cali-
brated step wedge discussed in Section 6.2 were two precision
resolution film targets of the standard Air Force 1951 type.
One, a medium contrast target, had a contrast ratio of 6.3:1
for a density difference (ΔD)of 0.8 between the lines and
the background. This condition is close to that of the
S082B spectra, where D_{max} (specular), is about 1.0 and
D_{min} about 0.1. An opaque line target on a clear background
was selected to correspond with the negative spectral lines
on the flight film. Resolution range of the target was one
to 228 line pairs per mm.

The second target was high contrast, with a contrast
ratio of 100:1 and ΔD = 2.0 or higher. An exposure of both
targets was obtained each time the wedge was photographed
(Table 6.1). Plate 1B168 was also photographed at the begin-
ning of each copy session to provide a standard by which to
judge loss of spectral detail from generation to generation
as subsequent contact prints were made.

Enlarged prints on Kodak polycontrast RC paper were
made from each copy generation and the flight film, from
in selected wavelength regions. Exposures were adjusted
slightly to achieve approximately equal densities from
each copy.

As could be seen from the enlarged paper prints, resolution was lost between the original film and the first copy. Compared with about 83 line pairs/mm resolution of the flight film, about 53 line pairs/mm could be resolved on the medium contrast targets of the copies. No significant differences among the copies up to 5th generation could be measured, except that slightly better resolution could be observed from the negative copy targets than with the positive copy targets. Slightly more resolution was lost in the high contrast targets, which averaged about 46 line pairs/mm.

6.4 Film Catalog

A complete listing of the SO82B exposures, Appendix B, is contained in a microfiche catalog of 5 parts located in pockets attached to this Guide. Table 6.3 is a sample sheet showing the film or plate number (each plate contains 8 exposures), day of year date of exposure, time of shutter opening, exposure duration, and pointing information in yaw, pitch, and roll. The data were derived from binary coded decimal information projected onto a film chip attached to each SO82B film strip. The time-of-day recorded by the diode array was mission elapsed time (MET) furnished by an ATM on-board computer. This computer time varied from Greenwich Mean Time (GMT) by as much as a few seconds and required periodic updates by ground command. The times listed in Appendix B have been corrected by the appropriate update information.

Pitch and yaw are given in arc sec, while roll is an arc min. For correct roll information, one must use the "Reconstructed Roll" referred to in several documents listed in Appendix A.

The column headed "off" gives the Pointing Reference System (PRS) limb offset in arc sec. A minus sign indicates a position on the solar disc. Fifty (50) indicates the PRS is off on in white light display state.

A zero (o) or one (1) in any one of the places in the "mode" 4 bit column had the following meanings:

```
                    X    X    X    X
Auto Step                              0 = NRL bias not in
            Auto        Flare          1 = NRL bias in
```

Errors that have been found to be diode array errors have been marked with a $ symbol. An exception to this symbol is that minus (-) offset errors are corrected with a plus (+) and are the only plus marks found in the log.

It will be noted that 4 cameras were used to supply the film for the 3 manned missions. The cameras and film traceability information, including development runs, are listed in Appendix C, Film Sequence Log, described in Section 4.2 of this Guide. The cameras carried film strips of the following numbers:

Camera	Film Strip or Plate No.	Mission
1.	1B001 - 1B201	SL-1/2
2.	2B001 - 2B201	SL-3
3.	2B301 - 1B501	SL-3
4.	3B001 - 3B201	SL-4

Other listings of the data are contained in documents described in Appendix A, Skylab Documentation.

Exposure times available for the automatic and flare mode operation of SO82B are given in Tables 6.4 and 6.5, respectively. Normal exposures on the solar disc were those listed under the "Zone 1" column. Times shown should be accurate to within a millisecond.

ATM Flight Film

Enlarged (1.8X)
Master Copy
Positive

NSSDC Contact
Working Negative

User's Positive

NSSDC Contact
Working Positive

User's Negative
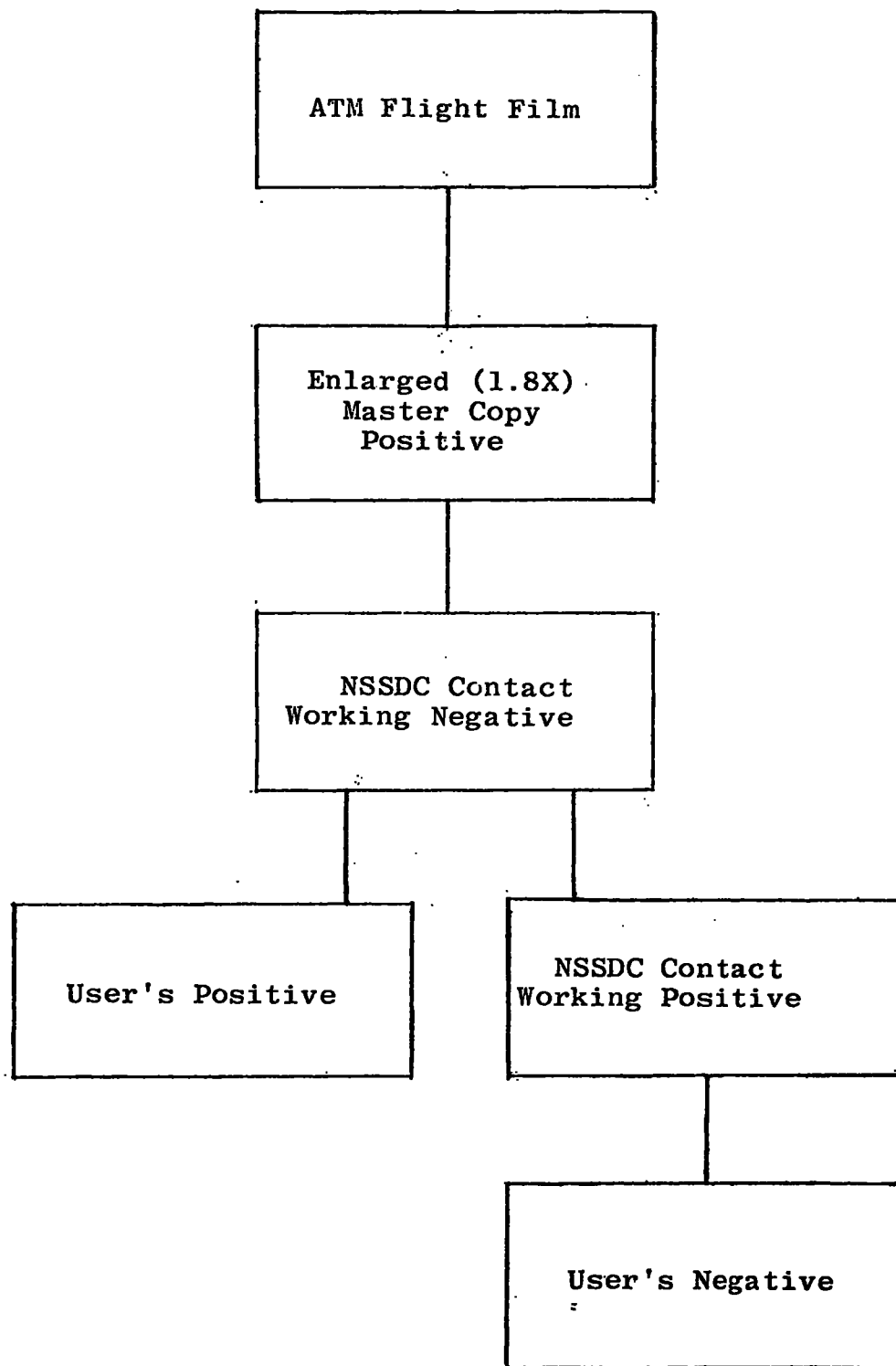
Fig. 6.1 — Duplication process for NRL/ATM photographic data

MASTER FILM
POSITIVE COPY
KODAK TYPE 2421
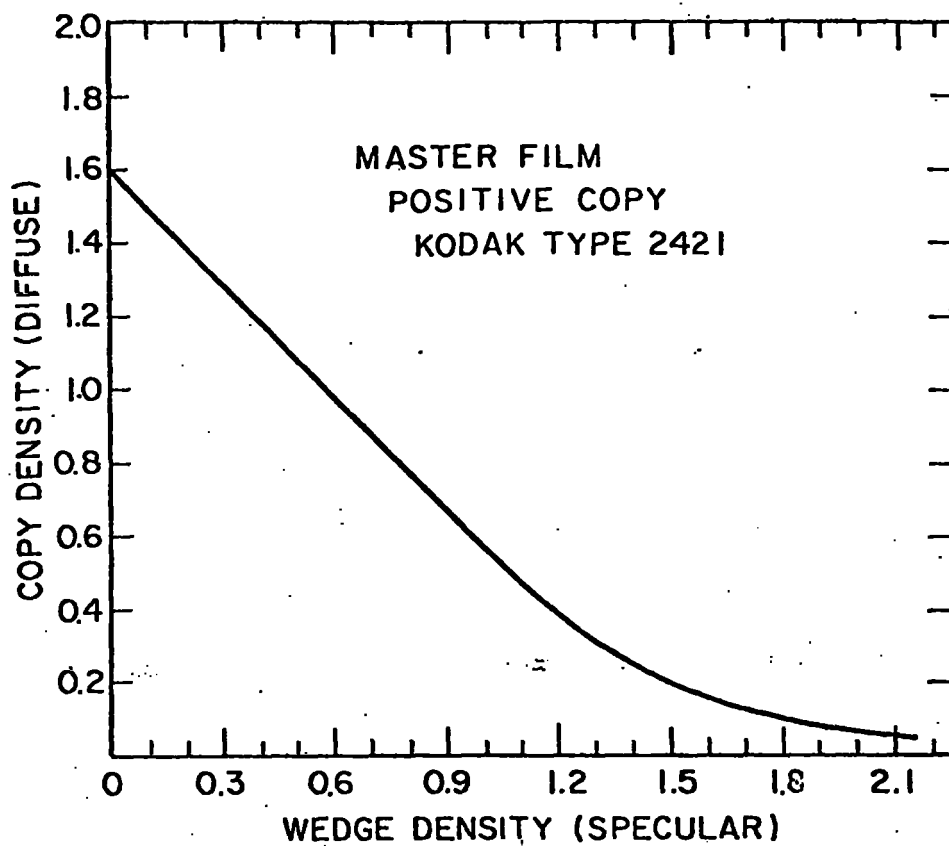
Fig. 6.2 — NSSDC archived master

TYPICAL USER'S COPIES

USER'S NEGATIVE

USER'S POSITIVE
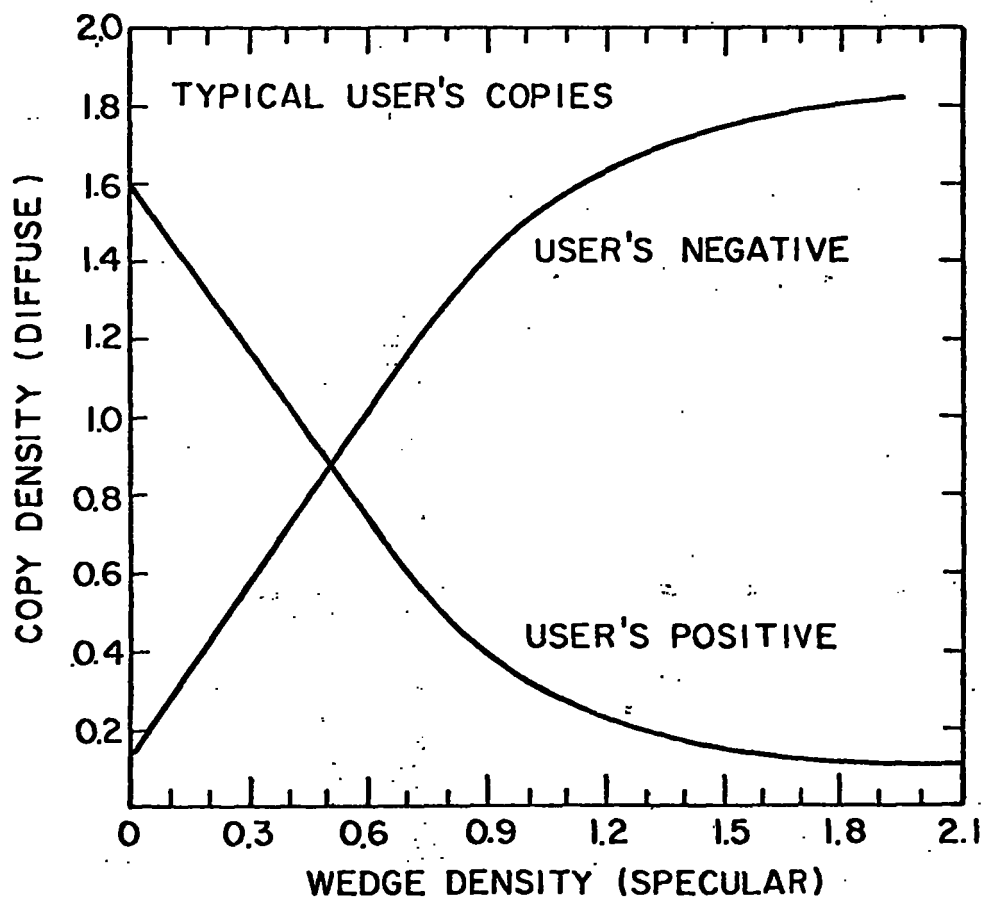
Fig. 6.3 — Transfer curves

6.3

Table 6.1   Location of Step Wedges Filmed with Groups of S082B Plates

Film Groups	Copy Roll*	Wedge Locations
1B001-1B015	2	<1B001, >1B015
1B016-1B030	2	<1B012, >1B030
1B031-1B080	3	<1B031, >1B080
1B081-1B140	3	<1B081
1B141-1B200	3	<1B141, >1B150, >1B165; <1B166, >1B200
1B201, 2B001-2B050	3	<1B201, >2B025, >2B050
2B051-2B100	3	<2B051; <2B076, >2B100
2B101-2B145	3	<2B101; <2B126
2B146-2B201	4	<2B146, <2B151; <2B161
2B301-2B350	4	<2B301, >2B350
2B351-2B400	4	<2B351, >2B400
2B401-2B444	4	<2B401, >2B440
2B445-2B501	4	<2B445, >2B501
3B001-3B095	4	<3B001, >3B025, >3B050; <3B051, >3B075
3B096-3B100	5	<3B096
3B101-3B125	5	<3B101, >3B125
3B126-3B201	5	<3B126; <3B151; <3B176; <3B201

*, Copy film was Eastman Kodak type 2421, in 4 different rolls, all of same batch numbers.

< Exposure just prior to XBXXX plate

> Exposure just after XBXXX plate.

; Pause in exposure of plates just prior to next wedge listed.

  Time lapse of 1 hour to overnight may exist between wedges.

STRIP NR	DOY	HR/MN/SEC	EXPTIME	YAW	PITCH	ROLL	OFF	MODE
2B121-1	228	18/38/14.75	0.25	-966.	-7.	10210.	50.	0101
2B121-2	228	18/38/17.00	10.00	-966.	-7.	10210.	50.	0101
2B121-3	228	18/38/28.75	1.25	-966.	-7.	10210.	50.	0101
2B121-4	228	18/38/32.00	40.00	-966.	-7.	10210.	50.	0101
2B121-5	228	18/39/13.75	5.00	-966.	-7.	10210.	50.	0101
2B121-6	228	18/39/20.75	160.00	-966.	-7.	10210.	50.	0101
2B121-7	228	18/42/ 2.50	20.00	-966.	-7.	10207.	50.	0101
2B121-8	228	18/50/18.25	359.50	-984.	0.	10143.	50.	0001
2B122-1	228	19/59/26.75	958.75	-969.	2.	10287.	25.	0001
2B122-2	228	20/17/48.00	602.25	-969.	22.	9497.	25.	0001
2B122-3	228	21/11/49.25	2.50	-944.	-31.	-7793.	-13.	1001
2B122-4	228	21/11/53.50	0.25	-944.	-31.	-7793.	-12.	1001
2B122-5	228	21/11/55.75	10.00	-944.	-31.	-7793.	-12.	1001
2B122-6	228	21/12/ 7.75	1.25	-944.	-31.	-7793.	-12.	1001
2B122-7	228	21/12/10.75	40.00	-944.	-31.	-7793.	-11.	1001
2B122-8	228	21/12/52.50	5.00	-944.	-31.	-7793.	-12.	1001
2B123-1	228	21/13/ 1.25	159.75	-944.	-31.	-7793.	-12.	1001
2B123-2	228	21/15/43.00	19.75	-944.	-31.	-7793.	-12.	1001
2B123-3	228	21/16/ 4.75	2.50	-944.	-31.	-7793.	-3.	1001
2B123-4	228	21/16/ 9.00	0.50	-944.	-31.	-7793.	-4.	1001
2B123-5	228	21/16/11.25	10.00	-944.	-31.	-7793.	-4.	1001
2B123-6	228	21/16/23.00	1.25	-944.	-31.	-7793.	-4.	1001
2B123-7	228	21/16/26.00	40.00	-944.	-31.	-7793.	-4.	1001
2B123-8	228	21/17/ 8.00	4.00	-944.	-31.	-7793.	-4.	1001
2B124-1	228	21/17/16.50	160.00	-944.	-31.	-7793.	-4.	1001
2B124-2	228	21/19/58.25	20.00	-944.	-31.	-7793.	-4.	1001
2B124-3	228	21/20/20.00	2.50	-944.	-31.	-7793.	-2.	1001
2B124-4	228	21/20/24.50	0.00$	-944.	-31.	-7793.	-2.	1001
2B124-5	228	21/20/26.75	10.00	-944.	-31.	-7793.	-1.	1001
2B124-6	228	21/20/38.50	1.25	-944.	-31.	-7793.	-2.	1001
2B124-7	228	21/20/41.50	40.00	-944.	-31.	-7793.	-2.	1001
2B124-8	228	21/21/23.50	4.50	-944.	-31.	-7792.	-2.	1001
2B125-1	228	21/21/32.00	160.00	-944.	-31.	-7793.	-2.	1001
2B125-2	228	21/24/13.75	20.00	-944.	-31.	-7793.	-2.	1001
2B125-3	228	21/24/35.50	2.50	-944.	-31.	-7793.	0.	.1001
2B125-4	228	21/24/39.75	0.50	-944.	-31.	-7793.	-1.	1001
2B125-5	228	21/24/42.00	10.00	-944.	-31.	-7793.	0.	1001
2B125-6	228	21/24/53.75	1.25	-944.	-31.	-7793.	-1.	1001
2B125-7	228	21/24/56.75	39.25	-944.	-31.	-7793.	0.	1001
2B125-8	228	21/25/38.75	5.00	-944.	-31.	-7793.	0.	1001

Table 6.3

STEP DENSITIES OF KODAK CALIBRATED WEDGE

Step	Density	
	Specular*	Diffuse+
1	.135	.12
2	.275	.22
3	.400	.32
4	.535	.42
5	.660	.51
6	.795	.61
7	.935	.71
8	1.06	.81
9	1.19	.91
10	1.32	1.00
11	1.44	1.10
12	1.58	1.20
13	1.72	1.30
14	1.84	1.39
15	1.99	1.50
16	2.09	1.58
17	2.21	1.68
18	2.35	1.78

* Measured with Grant Microdensitometer
  (above clear film step)
+ Kodak Calibration

Table 6.4 AUTO MODE EIGHT EXPOSURE SEQUENCE

Exposure Number	ZONE 1 Duration (Sec) LW	SW	ZONE 2 Duration (Sec) LW	SW	ZONE 3 Duration (Sec) LW	SW
1	.312		2.5		4.0	
2		2.5		10.0		16.0
3	1.25		10.0		16.0	
4		10.0		40.0		64.0
5	5.0		40.0		64.0	
6		40.0		160.0		256.0
7	20.0		160.0		256.0	
8		160.0			640.0	1024.0
	253 Sec	4.2 Min	1076 Sec	17.9 Min	1714 Sec	28.6 Min

LW: Long Wavelength Range
SW: Short Wavelength Range

Zone 1:   Sun Center to +1 arc sec or with PRS Off or in WL Display
Zone 2:   +2 to +9 arc sec off limb and in Limb Scan or Limb PTG
Zone 3:   +10 arc sec or greater off limb and in Limb Scan or Limb PTG
Moving from Zone 1 to Zone 2 increases exposure by factor of 4
Moving from Zone 2 to Zone 3 increases exposure by factor of 1.6

Table 6.5 SO82B FLARE MODE, 48 Exposure Sequence

(12.8 min)

Exp No.	WL	Duration (Sec)	Exp No.	WL	Duration (Sec)	Exp No.	WL	Duration (Sec)
1	S	0.312	17	S	0.321	33	S	1.250
2	S	1.250	18	S	1.250	34	S	5.000
3	S	5.000	19	S	5.000	35	S	20.000
4	S	20.000	20	S	20.000	36	S	80.000
5	S	0.312	21	L	0.156	37	L	0.156
6	S	1.250	22	L	0.625	38	L	0.625
7	S	5.000	23	L	2.500	39	L	2.500
8	S	20.000	24	L	10.000	40	L	10.000
9	S	0.156	25	S	1.25	2 min wait		
10	S	0.625	26	S	5.000	41	S	1.250
11	S	2.500	27	S	20.000	42	S	5.000
12	S	10.000	28	S	80.000	43	S	20.000
13	S	0.312	29	L	0.156	44	S	80.000
14	S	1.250	30	L	0.625	45	L	0.256
15	S	5.000	31	L	2.500	46	L	0.625
16	S	20.000	32	L	10.000	47	L	2.500
			2 min wait			48	L	10.000

7.0 OBSERVING PROGRAMS*

In support of the ATM experiments carried out from Skylab, a number of large and important programs of solar research were carried out from the ground, both by solar observations all over the world, and by experiments flown in rockets. In addition, a complex plan was developed for coordinating the individual Skylab observations, to optimize the return from each instrument and to produce the most valuable observations for solar physics. As a result, a large number of instruments covering the spectrum from the visible to x-rays were brought to focus on given solar targets, such as flares, and many times more data were acquired than could otherwise have been gathered. Thus, a massive attack was made on problems of solar physics during Skylab's nine months, which might well be called "the year of the sun".

7.1 The Joint Observing Program

The Joint Observing Program (JOP) was devised to make it feasible to use simultaneously the maximum number of instruments to produce the most valuable solar results. The key to accomplishing this was to plan the observations in a way that offered the best chance of contributing to the solution of the most important problems in solar physics. A list was drawn up that covered the problems which the ATM instruments were expected to be most likely to explain, such as the mechanism for transfer of energy through the solar atmosphere, or the trigger mechanism of solar flares and what goes on during flares. Observations relevant to each of these problems were listed, instrument by instrument. From this analysis, a set of JOP's was developed that came close to making use of every experiment during all the time allotted to ATM. There were many constraints because the observations desired for one instrument were often not compatible with those for another. The complex set of TOP's took the form of an illustrated manual containing detailed instructions for the operation of each JOP, of which there were 13 in SL-2. To implement the JOP's, a further subdivision into "building blocks" (BB), or elemental operational sequences, was required. There were 23 building blocks, which could be combined so as to carry out any of the JOP's. A small portion of this manual, actually about one percent, is reproduced in Figure 7.1.

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*Material for this section has been extracted from a paper by R. Tousey, Applied Optics 16, 825, 1977, Apollo Telescope Mount of Skylab: an Overview".

In planning the JOPs during the mission, the prevailing solar conditions were first considered. Once decided between, for example, active regions, JOP-2, or limb scans, JOP-5, the building blocks were chosen to accomplish the particular JOP in the best way. Time blocks were controlled to one minute units, and since the time available per orbit was a maximum of 55 minutes, and often much less, the perfect fit was rare.

The JOP system worked so well in SL-2 that the number of JOP's was increased in the following missions, reaching 27 for SL-4. In addition, so much confidence in the crew was developed that by late SL-4 free time was given to them in substantial amounts for observing events of opportunity which appeared to be of interest - the so-called "shopping list". Appendix A of this Guide contains a description of the JOP Summary Sheets available at NRL as a reference document and an abbreviated listing of the JOPS for SL-3.

7.2 The Calibration Rocket Program - CALROC

Accuracy of calibration of instrumentation used in the extreme ultraviolet has always been a problem of extreme difficulty, yet its importance for solar research cannot be underestimated. Early in the ATM program it was proposed by HCO and by NRL that their instruments be calibrated by reference to carefully standardized instrumentation flown in rockets. One rocket flight per mission for each institution was the minimum acceptable because the sensitivity of the ATM instruments was expected to change during the course of the nine months over which they would be used. The fundamental idea was to make at the same time the same measurements of solar radiation using both the rocket-borne and the ATM instruments. The rocket instruments had been carefully and recently calibrated before flight. Therefore they could be used to "standardize" the sun so that it could serve as a standard source with which to calibrate the ATM instruments.

The plan of NRL was to fly instruments almost exactly like those of ATM but reduced in size by a factor of two. The Harvard CALROC instrument was designed in a similar fashion. NRL, together with BBRC and the Ames Research Center, developed a command system by which the instrumentation section, after separation from the booster, could be pointed at particular places on the sun. This was done by a radio command link, combined with a television system that permitted the PI on the ground to watch a display showing in real time the sun's image in H-α on the slit plate of the rocket instrument and the precise location of the slit on the sun.

The CALROC program required a great effort but the results proved to be highly successful. In addition to being essential for ATM, the project served also to provide for the scientific community in general vehicles of much greater sophistication for use in ongoing solar research than were available prior to Skylab.

Section 5 of this Guide deals with the calibration results from the program.

7.3 Solar Forecast Services

It was extremely important not only for planning purposes but also for making changes in near real time in the observing program being conducted by the ATM crewman to have up-to-the-minute information on solar activity. Although the crewman himself could observe changes in solar activity in real time, it was hardly possible for the crew to maintain the continuous monitoring of the sun necessary to detect all events because time was required for other activities and for sleeping. Monitoring on a 24 hour basis was done through the network of ground-based solar observatories maintained by the National Oceanic and Atmospheric Administration (NOAA) with support from the Air Weather Service and with information sent to them by other observatories all over the world.

NOAA solar forecasters were stationed in the ATM control center around the clock. They made an invaluable contribution by providing timely and complete knowledge of solar conditions to the ATM team who prodiced the detailed planning of the observing program, and also to the ATM science Czar in the ATM mission control center.

Complete information on the sun was made a matter of record by NOAA. All this material was distributed to each ATM PI after the completion of the mission for use in the interpretation of the data gathered by his solar instruments in ATM. Appendix A lists this data available among the reference material at NRL.

7.4 Skylab Associated Solar Programs

Many associated solar programs were carried on for the most part by ground-based observatories and to a lesser extent by space experimentation. The Coordinated Observing Program (COP) spearheaded by HCO, made contonuously available by radio broadcast the observations actually being carried out by ATM together with those planned for the following day. This information was received by as many as 250 different groups located all over the world. Separate from this was the Skylab

ground-based astronomy program through which some eight
or ten major observatories were funded to make specialized
observations of a character closely related to the objec-
tives of the ATM experiments. In addition, there was the
ATM guest investigator program. This took the form of
proposals from a large number of solar physicists and
astronomers to provide post-mission relevant observational
material or specialized interpretative skills in exchange
for data gathered by ATM. In effect the guest investigator
program was simply a large collection of agreements between
collaborating scientists and PI's to share data. These
various collaborative programs have proved to be most
rewarding.

As a new experiment in collaboration, NASA, through
the NSF and NCAR, has provided support for a series of
Skylab Workshops which commenced in October 1975. These
Workshops were organized by the High Altitude Observatory.
The first was devoted to the study of coronal holes and
the second dealt with the problem of explaining the flare
mechanism.

Figure Captions

Fig. 7.1 A sample section from the volume that contained
detailed instructions to the crew concerning the
operation of the ATM instruments. The top section
is the first step in JOP 2B, at the right are listed
setup times (SU), operation times, and total elaspsed
times, in this case 44 min. The Building Blocks
(BB) are shown in the lower left, and operation A-E
are defined in the five columns. The sample H-α
image shows suggested slit positions for SO82B with
the SO55 square slit located at its center.

Step	BB	Target	ΔT/ΣΔT
(1)	4A	● Roll 82A XUV dispersion clear of active region. ● Point 55 OFFSET so that 55 MAR covers most of active region. ●. Record pointing coordinates RL+/- _____ U+/D- _____ L-/R+. _____ .	SU: 4 7/10
	B	● Point Hα1 at a Hαbright point. ● Roll slit for uniform emission. ● Maximize DET 1 or 3.	SU: 3 6/20
	C	● Repeat B at a second Hα1 bright point.	SU: 3 6/29
	D	● Point Hα1 at a relatively dark Hα area. ● Roll 82B slit for uniform emission.	SU: 2 5/36
	E	● Pointing and roll same as 4A. ● Repoint 82B slit for uniform emission.	SU: 2 6/44

Fig. 2 A sample section from the volume that contained detailed instructions to the crew concerning the operation of the ATM instruments. The top section is the first step in JOP 2B, at the right are listed setup times (SU), operation times, and total elaspsed times, in this case 44 min. The Building Blocks (BB) are shown in the lower left, and operations A-E are defined in the five columns. The sample H-α image shows suggested slit positions for S082B with the S055 square slit located at its center.

8.0   SPECTRAL ATLAS*

Atlases of the solar ultraviolet radiation have been
presented for the wavelength region 2226 – 2992 A by Tousey
et al. (1) and for the region 2988 – 3629 A by Brueckner
(2). However, correspondingly complete information on line
profiles and continua with good spectral resolution and
reliable calibration of absolute intensity have not been
published for wavelengths below 2226 A. Data from the CALROC
program, which had good absolute intensity calibration,
have been used to compile "A Spectral Atlas of the Sun
between 1175 and 2100 A". This Atlas is available in three
forms: an 8x10 inch document, NRL Report 8056; a 12x21
inch hardbound volume, NRL Report 8057; and magnetic com-
puter tapes, World Data Center – A for Rockets and Satellites
identification number RS-12A.

The atlas presents the absolute intensity of two quiet
regions, one located 300" inside the solar limb (cos θ = 0.73)
and representative of the spectrum of most of the disk. The
other quiet region is located 50" inside the limb (cos   =
0.32) and is more representative of a limb spectrum. In
addition, the spectrum of active region McMath 508 is pre-
sented for wavelengths longer than 1680 A. The logarithm of
the specific intensity in erg cm^{-2} s^{-1} sr^{-1} A^{-1} is plotted
vs wavelength in Angstroms. The 'spectra of the quiet regions
and the active region are plotted above each other on the
same page. This facilitates comparison of details in the
three types of spectra. The wavelength axis is marked in
.1A intervals and logarithmic intensity levels are labeled
in .10 intervals.

For wavelengths below 1400 A only isolated emission
lines are displayed. The continuum between lines is too
weak to be recorded even with the longest exposure times
(see Table 8.1). For wavelengths below 1200 A only the
emission lines at the limb position (50") are shown; the
corresponding spectral features on the disk (300") fall
below the detection limit. The active region spectrum is
shown only at wavelengths above 1680 A because exposure
conditions during flight did not permit reliable calibration
for shorter wavelengths.

Information on the exposures used to prepare the Atlas
is given in Table 8.1. For the exposures at 50" inside
the limb and in the active region, the full spatial resolu-
tion of the instrument (2" by 60") was used. During the

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*Material for this section has been obtained from NRL
Report 8056, (1976) "A Spectral Atlas of the Sun Between
1175 and 2100 Angstroms", by O. Kjeldseth Moe, M. E.
VanHoosier, J.-D. F. Bartoe, and G. E. Brueckner

exposures at 300" inside the limb the slit was moved back
and forth perpendicular to its length, covering an area of
about 60" by 60" on the solar disk. This was done to average
the inhomogeneous solar emission associated with the
chromospheric network.

The quiet solar regions were selected carefully to
avoid any solar activity, coronal holes, or filament channels.
In the case of the active region 90% of the slit was covered
by the plage. Figure 8.1 is a detailed drawing of the loca-
tion of the spectrograph slit inside the plage.

Intensity calibrations for the Atlas were made as
described in Section 5 of this Guide. The scans presented
in the atlas were smoothed by removing high-frequency noise
in the film emulsion and photometry using a Fourier filtering
technique described by Nicolas et al. (3) A low-frequency
component caused by grain clumps in the emulsion of size 10
 m could not be removed by filtering without degrading the
effective instrumental width. These grain clumps may distort
slightly the intensities and profiles. Broadening caused by
the instrument profile has not been removed from the atlas
spectra, because the shape of the instrument profile is not
known in enough detail. Furthermore, the low-frequency
noise component still present in the data may cause strong
distortions if deconvolution is attempted. One may estimate
the line widths from

$$\Delta \lambda_T \approx (\Delta \lambda_0^2 - \Delta \lambda^2)^{\frac{1}{2}}$$

where $\Delta\lambda_0$ is the observed line width, $\Delta\lambda$ the instrumental
width, and Δ_T the true width of the line profile.
Theoretical calculations using a ray-tracing method gave a
constant instrumental width of 0.055 A for all wavelengths
between 1200 and 2100 A. This should be regarded as a
lower limit since the effect of the film emulsion has not
been taken into account. From the width of the narrowest
emission lines in the spectrum, it seems more likely that
the effective instrumental width is 0.07 A.

The Ly α line presented a special problem. On the
1974 CALROC flight this line became seriously overexposed
in the line core, even for the shortest exposure times
at the 50" and 300" pointings. The central region (1 A
wide) of the line was therefore omitted from the atlas.
Fig. 8.2 is a sample page from the Atlas. The high resolution
spectra presented have been compared with results obtained
by others in order to evaluate the reliability of the
absolute intensities. In so doing, care was taken to
deresolve the CALROC spectra to fit the lower resolution
of the other investigators. The agreement is illustrated
in Fig. 8.3, showing the mean intensity of the sun averaged

over 10 A intervals as given by various observers. For
this figure the Atlas intensities at 300" inside the limb
were converted to solar mean intensities using the center-
to-limb variations given by Samain et al. (4). All the
intensities agree within the Atlas error limit of $\pm$ 25%.
A separate publication is being prepared listing the
intensities averaged over wavelength intervals ranging
from 0.1 to 10.0 A bandwidths.

8.1 References

1. R. Tousey, E. F. Milone, J. D. Purcell, W. Palm Schneider, and S. G. Tilford, "An Atlas of the Solar Ultraviolet Spectrum Between 2226 and 2992 Angstroms," NRL Report 7788, 1974.

2. G. Brueckner, Photometric Atlas of the Near Ultraviolet Solar Spectrum 2988 A-3629 A, Vandenhoeck and Ruprecht, Gottingen, 1960.

3. K. R. Nicolas, G. E. Brueckner, R. Tousey, D. A. Tripp, O. E. White, and R. G. Athay, submitted to Solar Physics (1977). *published(?) 1894*

4. D. Samain, R. M. Bonnet, R. Gayet, and C. Lizambert, Astron. Astrophys. 39, 71 (1975).

5. D. Samain and P. C. Simon, to be published in Solar Physics, (1977).

6. G. J. Rottman, Trans. Amer. Geophys. Union 56, 1157 (1974).

7. L. Heroux and R. A. Swirbalus, J. Geophys. Res. 81, 436 (1976).

Figure Captions

Fig. 8.1   Position of the spectrograph slit inside active region
McMath 508 on September 4, 1973.

Fig. 8.2   Sample Atlas Page

Fig. 8.3   Comparison of solar mean intensities averaged over
10 A intervals. The full line represent the NRL
CALROC data used in the atlas. Open circles are the
observations of Samain and Simon (5) crosses the obser-
vations of Rottman (6), and triangles the observations
of Heroux and Swirbalus (7).

Fig. 8.4   Sample page from Atlas.
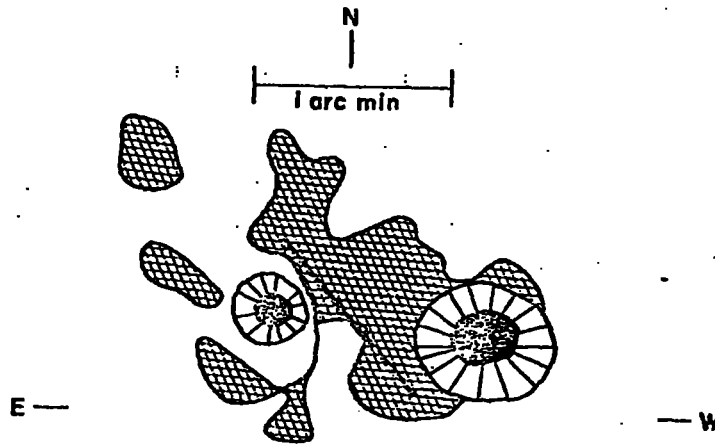
8.1

Fig. 3 — Position of the spectrograph slit inside active region
McMath 508 on September 4, 1973.

Fig 8.2 Sample Atlas page

8.3
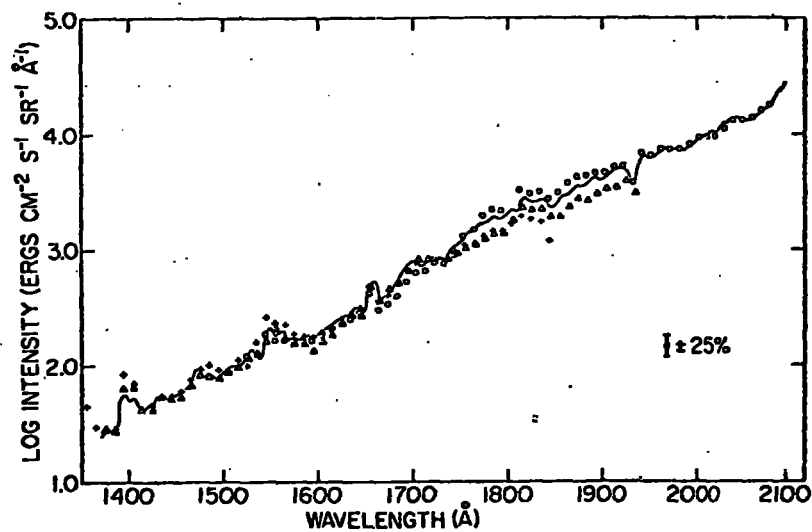
Fig. 4 — Comparison of solar mean intensities averaged over 10 Å
intervals. The full line represent the NRL CALROC data used in
the atlas. Open circles are the observations of Samain and Simon
[10], crosses the observations of Rottman [6], and triangles the
observations of Heroux and Swirbalus [7].
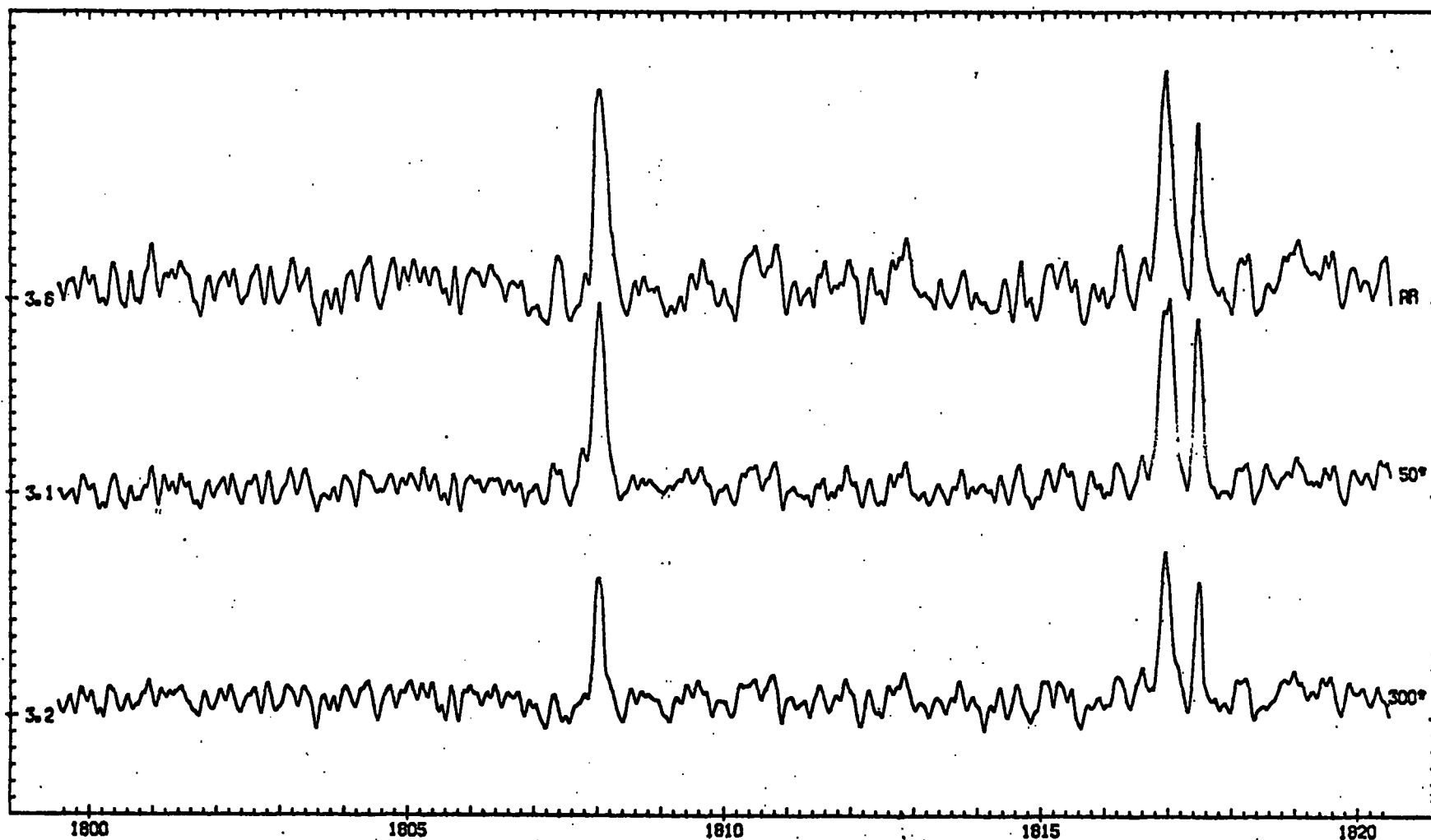
Fig 8.2 Sample page from atlas. (To be selected — probably not this one).

Table 8.1 — Data for Exposures Used to Make the Atlas

Date	Target	Exposure Time (s)	Altitude at Start of Exposure (km)
Sept. 4, 1973	Active Region	5.45	120.4
	McMath 508	1.07	111.3
Jan. 15, 1974	300" ± 30"	55.45	174.0
		1.95	218.7
		9.45	220.1
		31.45	224.8
	50"	39.45	234.2
		3.45	230.6
		9.45	227.4
		111.45	225.9

APPENDIX A. Skylab Documentation*

(1) NRL/ATM Exposure Catalog

> Vol. I (Rev A)   Time Listing
> Vol. II (Rev A)   Joint Observing Program Listing
> Vol. III (Rev A)   Target Listing
>
> These three volumes list the time, JOP, step and building
> block, the target, exposure time and wavelength band of
> each S082A (and S082B) exposure. They also include notes
> identifying special events, sequences and pointings.

(2) NRL/ATM Mission Engineering Data Book (Rev A)

> This catalog (one volume for each of the four S082B cameras)
> lists: the opening and closing time of the camera shutter
> for each exposure and the corresponding exact exposure time,
> wavelength band, and instrument operating mode; other
> instruments operating at the time, and their modes; and a
> verification of correct temperatures throughout the S082B
> instrument during the exposure.
>
> For each exposure, the values are also given for the recon-
> structed ("correct") ATM roll position, ROLL or Γ_{RR} , the
> maximum excursion of any disturbance in the ATM pointing
> position during the exposure, the S082B BIAS, the beta angle
> of the Skylab orbit, the altitude of the Skylab and its line
> of sight to the sun, and the orbit number.
>
> This catalog also includes traceability charts for each film
> strip, the temperature and radiation histories of each
> camera, and transmission curves and pinhole maps for each
> aluminum filter.

(3) ATM Mission Operation Log (Vols. 1-5, and magnetic tape)

> This catalog, prepared for S055, lists the time, pointing,
> operating modes and other information, for all observations
> by every ATM instrument (S052, S054, S055, S056, S082A,
> S082B and Hα1).
>
> It should be noted that the ATM roll position values
> throughout this catalog are not the reconstructed
> ("correct") values.

(4) User's Guide for Reconstructed Roll Reference (Γ_{RR})

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* This Appendix was prepared by N. Paul Patterson, Ball Brothers
  Research Corporation.

(5)   <u>Reconstructed Roll Reference Data</u> (6 vols.)

(6)   <u>Roll Reference Determination Summary Report</u>

(7)   <u>Skylab Apollo Telescope Mount Pointing Reference Handbook</u> .

The first three of these documents provide information from
which a user can determine the correct value of the ATM roll
position (Γ_{RR} = GAMMARR=EXP ROLL=ROLL), and ascertain its un-
certainty ($\sim \pm 40$ arc-min). The roll value corresponds to the
angle, in arc-min, between solar north and the UP pointing
axis of the ATM (parallel to the axis of the S082B slit, and
at right angles to the S055 raster lines). The error and
uncertainty of the telemetered values developed as a result `
of the failure of the star-tracker roll reference during the
mission.

The pointing bias required to coalign the center of the S082B
slit with the ATM fine sun-sensor, and its variation over the
mission is discussed in the fourth document.

(8)   <u>ATM JOP Summary Sheets (with Shopping Lists), SL 1/2, SL-3, SL-4</u>.

This set of documents consists of copies of plastic sheets
used by the astronaut operating the ATM control panel. These
sheets, with guidelines for their use in each of the JOPs,
provided explicit, self-contained, step-by-step instructions
for pointing and operating the ATM experiments in unison.
Photographic examples of solar features, and abbreviated
descriptions of desired pointings are shown together with
various combinations ("Building Blocks") of simultaneously
operated instrument modes. Each sheet summarized all the
information needed by Skylab crews and solar scientists to
coordinate observations with the daily scientific objectives.
A schedule was telemetered every morning to the crews, which
gave suggestions for observations and operating modes, and
guidelines for responding to flares and other interesting
events.

The sheets evolved through an iterative process, during many
months of practice on the ATM simulator, and much discussion
in meetings between scientists representing the ATM experi-
menter groups. The sheets changed from one manned phase
to the next. New JOPs were added, a few were dropped, and
the operating strategies were made more efficient and flex-
ible. JOP and step numberings are therefore not always
the same from one mission to another. A simplified listing
of Joint Observing Programs for SL-3 follows:

JOP 1	Chromospheric Network		JOP 10	Lunar Libration Clouds
JOP 2	Active Regions		JOP 11	Chromospheric Oscillations and Heating
JOP 3	Flares			
JOP 4	Prominences		JOP 12	Calibrations
JOP 5	Constant Latitude Studies		JOP 13	Night Sky Objects
JOP 6	Synoptic Observations		JOP 14	Eclipse (deleted for SL-3)
JOP 7	Atmospheric Extinction		JOP 15	Coronal Holes
JOP 8	Coronal Transients		JOP 16	Disk Transients
JOP 9	Solar Wind		JOP 17	Bright Points

Because of the formality of the NASA mission protocol which regulated the implementation of the JOP programs, a sheet of informal "Shopping List" items was included on each of the last two manned phases. These provided the astronaut with a list of pet projects for each of the experimenter groups, that he could conduct at his discretion when time was available.

(9)   ATM Experiments Reference Book (SL 1/2, SL-3, SL-4)

This document is a copy of a book used as a training text and carried on board Skylab for crew reference during each manned phase. It provides a detailed discussion of the background, rationale and scientific objectives of each of the JOPs. Specific terms are defined, and photographs are given of features as they would appear in H and XUV emissions. Graphs and tables of filter transmissions, detector positions of XUV lines, and other information useful to the ATM operator are included. In addition, technical data is included on each of the ATM instruments and monitors, as well as teleprinter abbreviations, and ATM scheduling conventions.

(10)   NOAA/Skylab Solar Data Books

Several dozen loose-leaf volumes containing copies of the solar photographs and data provided ATM experimenters by NOAA during the Skylab mission.

(11)   Skylab ATM H-Alpha Atlas, and Atlas Guide (49 vols.)

Copies of photographs taken by the $H\alpha$ telescope on ATM ($H\alpha$1). A print is included with a scale of 2 arc-min per inch, for the beginning and end of each orbit, for each significant ATM pointing change, and, when no pointing change occurred, at 15 minute intervals, for the entire Skylab mission.

(12) **NRL Science Console Execution Log Books**

Roughly two dozen loose-leaf volumes containing information
pertinent to the operation of NRL's two instruments on the
ATM, logged in real-time by NRL representatives who manned
consoles in the mission control center round-the-clock.
These logs contain summary charts of the orbits in which
the ATM was operated, and the as-flown schedule of ATM oper-
ations relative to orbital sunrise and sunset. Of particular
value to users of S082B data, are notes of crew-reported
solar events, operating errors, and special observations with
the S082B instrument.

(13) **Skylab Astronaut-Ground Voice Transcripts**

This is a complete set of all voice communication between the
Skylab astronauts and the ground, of both live conversations
and comments taped on an onboard recorder and dumped. In
addition, a set of transcripts is available edited for ATM-
related communications.

(14) **Skylab Operational Handbook, (Vol. I and II)**

Detailed diagrams of ATM instruments, as well as the ATM, and
the checklists of their operating procedures.

Camera No B1 SL 1/2
Sequence Log

ATM No	Roll	Strip Cut	Dev Run	ATM No	Roll	Strip Cut	Dev Run	ATM No	Roll	Strip Cut	Dev Run	ATM No	Roll	Strip Cut	Dev Run
1B001	6A-3		3	1B051	8A-40			1B101	7B-11			1B151	7A-33		
1B002	3		1	1B052	8A-41			1B102	7B-10			1B152	7A-32		
1B003	7B-62			1B053	8A-42			1B103	7B-09		3	1B153	7A-31		
1B004	7B-63			1B054	8A-43			1B104	7B-8		5	1B154	7A-30		
1B005	7B-64			1B055	8A-44			1B105	7B-7			1B155	7A-29		
1B006	7B-65			1B056	8A-45			1B106	7B-6			1B156	7A-28		
1B007	7B-66			1B057	8A-46			1B107	7B-5			1B157	7A-27		
1B008	7B-67			1B058	8A-48			1B108	7A-80			1B158	7A-26		
1B009	7B-69			1B059	8A-49			1B109	7A-79			1B159	7A-24		
1B010	7B-70			1B060	8A-50			1B110	7A-78			1B160	7A-23		
1B011	7B-71			1B061	8A-51			1B111	7A-77			1B161	7A-22		
1B012	7B-72			1B062	8A-52			1B112	7A-76			1B162	7A-21		
1B013	7B-73			1B063	8A-53			1B113	7A-75			1B163	7A-20		
1B014	7B-74			1B064	8A-54			1B114	7A-74			1B164	7A-19		
1B015	7B-75			1B065	8A-55			1B115	7A-73			1B165	7A-18		
1B016	7B-76			1B066	8A-56			1B116	7A-72			1B166	7A-17		
1B017	7B-77			1B067	8A-57			1B117	7A-71			1B167	7A-16		
1B018	7B-78			1B068	8A-59			1B118	7A-69			1B168	7A-14		
1B019	8A-5			1B069	8A-60			1B119	7A-68			1B169	7A-13		
1B020	8A-6			1B070	8A-61			1B120	7A-67			1B170	7A-12		
1B021	8A-7			1B071	8A-62			1B121	7A-66			1B171	7A-11		
1B022	8A-8			1B072	8A-63			1B122	7A-65			1B172	7A-10		
1B023	8A-9			1B073	8A-64			1B123	7A-64			1B173	7A-9		
1B024	8A-10			1B074	8A-65			1B124	7A-63			1B174	7A-8		
1B025	8A-11			1B075	8A-66			1B125	7A-62			1B175	7A-7		
1B026	8A-12			1B076	8A-67			1B126	7A-61			1B176	7A-6		
1B027	8A-13			1B077	8A-68			1B127	7A-60			1B177	7A-5		
1B028	8A-14			1B078	8A-70			1B128	7A-58			1B178	7B-37		
1B029	8A-16			1B079	7B-35			1B129	7A-57			1B179	7B-38		
1B030	8A-17			1B080	7B-34			1B130	7A-56			1B180	7B-38		
1B031	8A-18			1B081	7B-33		2	1B131	7A-55			1B181	7B-40		4
1B032	8A-19			1B082	7B-32		3	1B132	7A-54			1B182	7B-41		3
1B033	8A-20			1B083	7B-31			1B133	7A-53			1B183	7B-42		4
1B034	8A-21			1B084	7B-30			1B134	7A-52			1B184	7B-43		
1B035	8A-22			1B085	7B-29			1B135	7A-51			1B185	7B-44		
1B036	8A-23			1B086	7B-28			1B136	7A-50			1B186	7B-45		
1B037	8A-24			1B087	7B-27			1B137	7A-49			1B187	7B-46		
1B038	8A-26			1B088	7B-26			1B138	7A-47			1B188	7B-48		
1B039	8A-27			1B089	7B-24			1B139	7A-46			1B189	7B-49		
1B040	8A-28			1B090	7B-23			1B140	7A-45			1B190	7B-50		
1B041	8A-29		1	1B091	7B-22			1B141	7A-44			1B191	7B-51		
1B042	8A-30		2	1B092	7B-21			1B142	7A-43		5	1B192	7B-52		
1B043	8A-31			1B093	7B-20			1B143	7A-42		4	1B193	7B-53		
1B044	8A-32			1B094	7B-19			1B144	7A-41			1B194	7B-54		
1B045	8A-33			1B095	7B-18			1B145	7A-40			1B195	7B-55		
1B046	8A-34			1B096	7B-17			1B146	7A-39			1B196	7B-56		
1B047	8A-35			1B097	7B-16			1B147	7A-38			1B197	7B-58		
1B048	8A-37			1B098	7B-14			1B148	7A-36			1B198	7B-59		
1B049	8A-38			1B099	7B-13			1B149	7A-35			1B199	7B-60		
1B050	8A-39		1	1B100	7B-12			1B150	7A-34			1B200	7B-61		
												1B201	6A-2		3

Film Roll No	Data Film Type
7A	104-06-04
7B	104-06-04
8A	104-06-04
6A	104-06-04
3	101-06-04

Camera No. B2

Sequence Log

ATM No.	Roll	Strip Cut	Dev Run
2B001	3		1
2B002	2	25	A
2B003	2	24	1
2B004	2	23	
2B005	2	22	
2B006	2	21	
2B007	2	20	
2B008	2	19	
2B009	2	18	
2B010	2	17	
2B011	2	16	
2B012	2	14	
2B013	2	13	
2B014	2	12	
2B015	2	11	
2B016	2	10	
2B017	2	9	
2B018	2	8	
2B019	2	7	
2B020	2	6	
2B021	2	5	
2B022	1	80	
2B023	1	79	
2B024	1	78	
2B025	1	77	
2B026	1	76	
2B027	1	75	
2B028	1	74	
2B029	1	73	
2B030	1	72	
2B031	1	71	
2B032	1	69	
2B033	1	68	
2B034	1	67	
2B035	1	66	
2B036	1	65	
2B037	1	64	
2B038	1	63	
2B039	1	62	
2B040	1	61	1
2B041	1	60	2
2B042	1	58	
2B043	1	57	
2B044	1	56	
2B045	1	55	
2B046	1	54	
2B047	1	53	
2B048	1	52	
2B049	1	51	
2B050	1	50	

ATM No.	Roll	Strip Cut	Dev Run
2B051	1	49	
2B052	1	47	
2B053	1	46	
2B054	1	45	
2B055	1	44	
2B056	1	43	
2B057	1	42	
2B058	1	41	
2B059	1	40	
2B060	1	39	
2B061	1	38	
2B062	1	36	
2B063	1	35	
2B064	1	34	
2B065	1	33	
2B066	1	32	
2B067	1	31	
2B068	1	30	
2B069	1	29	
2B070	1	28	
2B071	1	27	
2B072	1	25	
2B073	1	24	
2B074	1	23	
2B075	1	22	
2B076	1	21	
2B077	1	20	
2B078	1	19	
2B079	1	18	
2B080	1	17	2
2B081	1	16	3
2B082	1	14	
2B083	1	13	
2B084	1	12	
2B085	1	11	
2B086	1	10	
2B087	1	9	
2B088	1	8	
2B089	1	7	
2B090	1	6	
2B091	1	5	
2B092	2	37	
2B093	2	38	
2B094	2	39	
2B095	2	40	
2B096	2	41	
2B097	2	42	
2B098	2	43	
2B099	2	44	
2B100	2	45	

ATM No.	Roll	Strip Cut	Dev Run
2B101	2	47	
2B102	2	48	
2B103	2	49	3
2B104	2	50	5
2B105	2	51	
2B106	2	52	
2B107	2	53	
2B108	2	54	
2B109	2	55	
2B110	2	56	
2B111	2	57	
2B112	2	59	
2B113	2	60	
2B114	2	61	
2B115	2	62	
2B116	2	63	
2B117	2	64	
2B118	2	65	
2B119	2	66	
2B120	2	67	
2B121	2	68	
2B122	2	70	
2B123	2	71	
2B124	2	72	
2B125	2	73	
2B126	2	74	
2B127	2	75	
2B128	2	76	
2B129	2	77	
2B130	2	78	
2B131	2	79	
2B132	2	81	
2B133	2	82	
2B134	2	83	
2B135	2	84	
2B136	2	85	
2B137	2	86	
2B138	2	87	
2B139	2	88	
2B140	2	89	
2B141	2	90	
2B142	2	92	
2B143	2	93	
2B144	2	94	5
2B145	2	95	4
2B146	2	96	
2B147	2	97	
2B148	2	98	
2B149	2	99	
2B150	2	100	

ATM No.	Roll	Strip Cut	Dev Run
2B151	2	101	
2B152	3	5	
2B153	3	6	
2B154	3	7	
2B155	3	8	
2B156	3	9	
2B157	3	10	
2B158	3	11	
2B159	3	12	
2B160	3	13	
2B161	3	14	
2B162	3	16	
2B163	3	17	
2B164	3	18	
2B165	3	19	
2B166	3	20	
2B167	3	21	
2B168	3	22	
2B169	3	23	
2B170	3	24	
2B171	3	25	
2B172	3	27	
2B173	3	28	
2B174	3	29	
2B175	3	30	
2B176	3	31	
2B177	3	32	
2B178	3	33	
2B179	3	34	
2B180	3	35	
2B181	3	36	
2B182	3	38	
2B183	3	39	
2B184	3	40	4
2B185	3	41	3
2B186	3	42	
2B187	3	43	
2B188	3	44	
2B189	3	45	
2B190	3	46	
2B191	3	47	
2B192	3	48	
2B193	2	36	
2B194	2	34	
2B195	2	33	
2B196	2	32	
2B197	2	31	
2B198	2	30	
2B199	2	29	
2B200	2	28	
2B201	2	27	3

Film Data	
Roll No	Film Type
1	104-06-06
2	104-06-06
3	104-06-06
3	101-06-05

Camera No. B3
Sequence Log

ATM No.	Roll	Strip cut	Dev Run	ATM No.	Roll	Strip cut	Dev Run	ATM No.	Roll	Strip cut	Dev Run	ATM No.	Roll	Strip cut	Dev Run
2B301	3-56		1	2B351	18-14			2B401	17-6		3	2B451	16-36		4
2B302	3-57			2B352	18-16			2B402	17-5		5	2B452	16-34		
2B303	3-58			2B353	18-17			2B403	16-88			2B453	16-33		
2B304	3-(101)			2B354	18-18			2B404	16-87			2B454	16-32		
2B305	17-52			2B355	18-19			2B405	16-86			2B455	16-31		
2B306	17-53			2B356	18-20			2B406	16-85			2B456	16-30		
2B307	17-54			2B357	18-21			2B407	16-84			2B457	16-29		
2B308	17-55			2B358	18-22			2B408	16-83			2B458	16-28		
2B309	17-56			2B359	18-23			2B409	16-82			2B459	16-27		
2B310	17-57			2B360	18-24			2B410	16-81			2B460	16-26		
2B311	17-58			2B361	18-25			2B411	16-80			2B461	16-24		
2B312	17-60			2B362	18-27			2B412	16-79			2B462	16-23		
2B313	17-61			2B363	18-28			2B413	16-77			2B463	16-22		
2B314	17-62			2B364	18-29			2B414	16-76			2B464	16-21		
2B315	17-63			2B365	18-30			2B415	16-75			2B465	16-20		
2B316	17-64			2B366	18-31			2B416	16-74			2B466	16-19		
2B317	17-65			2B367	18-32			2B417	16-73			2B467	16-18		
2B318	17-66			2B368	18-33			2B418	16-72			2B468	16-17		
2B319	17-67			2B369	18-34			2B419	16-71			2B469	16-16		
2B320	17-68			2B370	18-35			2B420	16-70			2B470	16-14		
2B321	17-69			2B371	18-36			2B421	16-69			2B471	16-13		
2B322	17-71			2B372	18-38			2B422	16-68			2B472	16-12		
2B323	17-72			2B373	18-39			2B423	16-66			2B473	16-11		
2B324	17-73			2B374	18-40			2B424	16-65			2B474	16-10		
2B325	17-74			2B375	18-41			2B425	16-64			2B475	16-9		
2B326	17-75			2B376	18-42			2B426	16-63			2B476	16-8		
2B327	17-76			2B377	17-94			2B427	16-62			2B477	16-7		
2B328	17-77			2B378	17-95			2B428	16-61			2B478	16-6		
2B329	17-78			2B379	17-96			2B429	16-60			2B479	16-5		4
2B330	17-79			2B380	17-97		2	2B430	16-59			2B480	17-26		3
2B331	17-80			2B381	17-98		3	2B431	16-58			2B481	17-27		
2B332	17-82			2B382	17-99			2B432	16-56			2B482	17-28		
2B333	17-83			2B383	17-102			2B433	16-55			2B483	17-29		
2B334	17-84			2B384	17-24			2B434	16-54			2B484	17-30		
2B335	17-85			2B385	17-23			2B435	16-53			2B485	17-31		
2B336	17-86			2B386	17-22			2B436	16-52			2B486	17-32		
2B337	17-87			2B387	17-21			2B437	16-51			2B487	17-33		
2B338	17-88			2B388	17-20			2B438	16-50			2B488	17-34		
2B339	17-89		1	2B389	17-19			2B439	16-49		5	2B489	17-35		
2B340	17-90		2	2B390	17-18			2B440	16-48		4	2B490	17-36		
2B341	17-91			2B391	17-17			2B441	16-47			2B491	17-37		
2B342	18-5			2B392	17-16			2B442	16-45			2B492	17-39		
2B343	18-6			2B393	17-15			2B443	16-44			2B493	17-40		
2B344	18-7			2B394	17-14			2B444	16-43			2B494	17-41		
2B345	18-8			2B395	17-12			2B445	16-42			2B495	17-42		
2B346	18-9			2B396	17-11			2B446	16-41			2B496	17-43		
2B347	18-10			2B397	17-10			2B447	16-40			2B497	17-44		
2B348	18-11			2B398	17-9			2B448	16-39			2B498	17-45		
2B349	18-12			2B399	17-8			2B449	16-38			2B499	17-47		3
2B350	18-13			2B400	17-7			2B450	16-37			2B500	17-48		A
												2B501	17-49		1

Film Data

Roll No.	Film Type
16	104-06-05
17	104-06-05
18	104-06-05
3	104-06-06
3(101)	101-06-05

Camera No. B4
Sequence Log

ATM No.	Roll	Strip/Cut	Dev Run
3B001	8-55		4
3B002	8-54		
3B003	8-53		
3B004	8-52		
3B005	8-51		
3B006	8-50		
3B007	8-49		
3B008	8-47		
3B009	8-46		
3B010	8-45		
3B011	8-44		
3B012	8-43		
3B013	8-42		
3B014	8-41		
3B015	8-40		
3B016	8-39		
3B017	8-38		4
3B018	8-36		3
3B019	8-35		
3B020	8-34		
3B021	8-33		
3B022	8-32		
3B023	8-31		
3B024	8-30		
3B025	8-29		
3B026	8-28		
3B027	8-27		
3B028	8-25		
3B029	8-24		
3B030	8-23		
3B031	8-22		
3B032	8-21		
3B033	8-20		
3B034	8-19		
3B035	8-18		
3B036	8-17		3
3B037	8-16		1
3B038	8-14		
3B039	8-13		
3B040	8-12		
3B041	8-11		
3B042	8-10		
3B043	8-9		
3B044	8-8		
3B045	8-7		
3B046	8-6		
3B047	8-5		
3B048	9-5		
3B049	9-6		
3B050	9-7		

ATM No.	Roll	Strip/Cut	Dev Run
3B051	9-8		
3B052	9-9		
3B053	9-10		
3B054	9-11		
3B055	9-12		
3B056	9-13		
3B057	9-14		
3B058	9-16		
3B059	9-17		
3B060	9-18		
3B061	9-19		
3B062	9-20		
3B063	9-21		
3B064	9-22		
3B065	9-23		
3B066	9-24		
3B067	9-25		
3B068	9-27		
3B069	9-28		
3B070	9-29		
3B071	9-30		
3B072	9-31		
3B073	9-32		
3B074	9-33		
3B075	9-34		
3B076	9-35		
3B077	9-36		1
3B078	9-38		2
3B079	9-39		
3B080	9-40		
3B081	9-41		
3B082	9-42		
3B083	9-43		
3B084	9-44		
3B085	9-45		
3B086	9-46		
3B087	9-47		
3B088	9-49		
3B089	9-50		
3B090	9-51		
3B091	9-52		
3B092	9-53		
3B093	9-54		
3B094	9-55		
3B095	9-56		
3B096	9-57		
3B097	9-58		
3B098	9-60		
3B099	9-61		
3B100	9-62		2

ATM No.	Roll	Strip/Cut	Dev Run
3B101	9-63		4
3B102	9-64		
3B103	9-65		
3B104	9-66		
3B105	9-67		
3B106	9-68		
3B107	9-69		
3B108	9-70		
3B109	4-3		
3B110	4-4		
3B111	4-5		
3B112	4-6		
3B113	4-7		
3B114	4-8		
3B115	4-9		
3B116	4-10		
3B117	4-11		
3B118	4-13		
3B119	4-14		
3B120	4-15		
3B121	4-16		
3B122	4-17		
3B123	4-18		4
3B124	4-19		5
3B125	4-20		
3B126	4-21		
3B127	4-22		
3B128	4-24		
3B129	4-25		
3B130	4-26		
3B131	4-27		
3B132	4-28		
3B133	4-29		
3B134	4-30		
3B135	4-31		
3B136	4-32		
3B137	4-33		
3B138	4-35		
3B139	4-36		
3B140	4-37		
3B141	4-38		
3B142	4-39		
3B143	4-40		
3B144	4-41		
3B145	4-42		
3B146	4-43		
3B147	4-44		
3B148	4-45		
3B149	4-56		
3B150	4-55		

ATM No.	Roll	Strip/Cut	Dev Run
3B151	4-54		
3B152	4-53		
3B153	4-52		
3B154	4-51		
3B155	4-50		
3B156	4-49		
3B157	4-48		
3B158	4-47		
3B159	8-102		
3B160	8-101		
3B161	8-100		
3B162	8-99		
3B163	8-98		
3B164	8-97		5
3B165	8-96		1 / 3
3B166	8-95		
3B167	8-94		
3B168	8-93		
3B169	8-91		
3B170	8-90		
3B171	8-89		
3B172	8-88		
3B173	8-87		
3B174	8-86		
3B175	8-85		
3B176	8-84		
3B177	8-83		
3B178	8-82		
3B179	8-80		
3B180	8-79		
3B181	8-78		
3B182	8-77		
3B183	8-76		
3B184	8-75		3
3B185	8-74		2
3B186	8-73		
3B187	8-72		
3B188	8-70		
3B189	8-69		
3B190	8-68		
3B191	8-67		
3B192	8-66		
3B193	8-65		
3B194	8-64		
3B195	8-63		
3B196	8-62		
3B197	8-61		
3B198	8-60		
3B199	8-58		
3B200	8-57		
3B201	8-56		2

Film Data

Roll No	Film Type
8	104-06-08
9	104-06-08
4	101-06-10

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Appendix E. Line Lists for SO82B Data

The following tables have been extracted from the references given. Additional data concerning the measurements or theoretical techniques involved may be obtained from the published papers. References to studies of specific ions or solar phenomena may be found in the Bibliography, Appendix D.

E.1.1 (DFVB)

"The Emission Line Spectrum Above the Limb of the Quiet Sun: 1175-1940 Angstroms," G. A. Doschek, U. Feldman, M. E. VanHoosier and J.-D. F. Bartoe. Ap. J. Supp. Series 31, p. 417 (1976).

TABLE 2 (DFV13)

STRONG SOLAR LINES 4 ARC SECONDS ABOVE THE LIMB

Ion	λ (Å) (Lab)	λ (Å) (Solar)	Int.*	Ion	λ (Å) (Lab)	λ (Å) (Solar)	Int.*
C III	1174.933	1174.94	1.1	S IV	1404.77 }	1404.79	1.8
C III	1175.263	1175.27	0.90	O IV	1404.812 }		
C III	1175.590	1175.64	B2.0	S IV	1406.00	1406.04†	0.73
C III	1175.711	1175.73	B2.0	O IV	1407.386	1407.38	0.66
C III	1175.987	1175.99	B0.83	Ni II	1411.071	1411.05	0.14
C III	1176.370	1176.37	0.95	Fe II	1412.834	1412.83	0.14
S III	1190.17	1190.20†	0.088	S IV	1416.94	1416.92	0.36
		1190.49	0.046			1423.86	0.088
S III	1194.02	1194.07†	0.12	Fe II	1424.716	1424.71	0.13
S III	1194.40	1194.39	0.063	Fe II	1434.994	1434.98	0.10
Fe II	1194.66	1194.63**	0.063	Fe II	1442.746	1442.75	0.051
		1199.17	0.28	Si III	1447.196	1447.23	0.056
S III	1200.97	1200.97	0.43	Ni II	1454.852	1454.84	0.20
S III	1201.71	1201.73	0.056	C I	1459.032	1459.03	0.036
		1204.31‡	0.17	C I	1463.336	1463.34	0.11
Si III	1206.510	1206.52	2.5	Ni II	1467.265	1467.27	0.094
Lα	1215.67	1215.64	42	C I	1467.402	1467.40	0.075
O V	1218.406	1218.35§	2.9	Ni II	1467.762	1467.75	0.11
N V	1238.821	1238.82	3.6	S I	1472.972	1472.96	0.069
N V	1242.804	1242.81	2.0	S I	1473.995	1473.99	0.059
C III	1247.383	1247.38	0.14	C I	1481.763	1481.76	0.10
S II	1250.50	1250.58†	0.18	N IV	1486.496	1486.51	1.54
S II	1253.79	1253.81	0.35	N I	1492.625	1492.63	0.069
C I	1256.498	1256.47	0.034	Ni II	1500.437	1500.44	0.16
S II	1259.53	1259.52	0.43			1501.81	0.094
Si II	1260.421	1260.41	0.13	Ni II	1502.150	1502.15	0.094
Si II	1264.737	1264.74	0.33	Ni II	1510.859	1510.86	0.11
Si II	1265.001	1265.08	B0.16	Si II	1526.708	1526.71	0.58
C I	1274.984	1274.98	0.041	Si II	1533.432	1533.44	0.58
C I	1288.422	1288.42	0.041	Ni II	1536.746	1536.74	0.081
Si III	1294.543	1294.55	0.40	P II	1542.29	1542.31||	0.056
Si III	1296.726	1296.73	0.28	C IV	1548.185	1548.19	21.6
Si III	1298.891 } 1298.960 }	1298.94	1.2	Fe II	1550.260	1550.29	B
				C IV	1550.774	1550.79	14.1
		1300.90	0.046	Fe II	1551.933	1551.93	0.088
Si III	1301.146	1301.15	0.11	Fe II	1558.690	1558.62	B0.40
O I	1302.169	1302.17	1.24	Fe II	1559.084	1559.09	1.3
Si III	1303.320	1303.32	0.35	C I	1560.309	1560.30	0.34
Si II	1304.372	1304.37	0.24	C I	1560.69	1560.69	B0.35
O I	1304.857	1304.86	1.3	C I	1561.438	1561.42	0.39
Si II	1305.590	1305.58	0.063	Fe II	1563.788	1563.79	1.2
O I	1306.029	1306.03	1.3	Fe II	1565.374	1565.35	0.088
Si II	1309.277	1309.29	0.27	Fe II	1566.819	1566.82	0.81
C I	1311.363	1311.35	0.046	Fe II	1568.016	1568.02	0.31
Si III	1312.590	1312.58	0.16	Fe II	1569.674	1569.67	0.61
Ni II	1317.220	1317.21	0.25	Fe II	1570.242	1570.24	0.88
C II	1323.93	1323.92	B0.25	Fe II	1573.825	1573.83	0.35
C I	1328.833	1328.81	0.038	Fe II	1574.03	1574.02**	0.23
C I	1329.10	1329.14	B0.045	Fe II	1574.768	1574.78	B
C I	1329.59	1329.55	B0.048	Fe II	1574.923	1574.91	1.1
C II	1334.532	1334.53	4.0			1576.65	0.15
Ni II	1335.203	1335.21	B0.16	Fe II	1577.166	1577.16	0.28
C II	1335.707	1335.71	5.0	Fe II	1578.497	1578.49	0.088
P III	1344.34	1344.32||	0.051	Fe II	1580.625	1580.62	0.77
O I	1355.598	1355.58	0.78	Fe II	1584.949	1584.95	0.81
C I	1355.844	1355.83	0.069			1586.53	0.088
O I	1358.512	1358.49	0.18	Fe II	1588.286	1588.29	0.58
Fe II	1360.18	1360.16**	0.12	Fe II	1600.02	1600.01	0.088
Fe II	1361.372	1361.36	0.15	Fe II	1602.51	1602.51**	0.19
Fe II	1368.098	1368.07	0.075	Fe II	1605.318	1605.32	0.063
Ni II	1370.136	1370.12	0.21	Fe II	1608.456	1608.46	0.39
O V	1371.292	1371.29	0.70	Fe II	1610.921	1610.92	0.61
Fe II	1379.60	1379.60**	0.059	Fe II	1611.21	1611.19	0.28
Ni II	1381.295	1381.28	0.11	Fe II	1612.802	1612.81	1.0
Fe II	1387.22	1387.20	0.046	Fe II	1616.65	1616.65	0.069
Fe II	1392.82	1392.80	0.094	Fe II	1618.470	1618.47	0.28
Ni II	1393.330	1393.33	B	Fe II	1621.24	1621.25**	0.081
Si IV	1393.755	1393.76	15.6	Fe II	1621.685	1621.69	0.21
O IV	1397.20	1397.20	0.24	Fe II	1621.85	1621.83**	B
O IV	1399.774	1399.77	0.68	Fe II	1623.091	1623.09	0.49
O IV	1401.156	1401.16	4.6	Fe II	1623.715	1623.71	0.094
Si IV	1402.770	1402.78	10.8	Fe II	1625.520	1625.52	1.12

TABLE 2—*Continued* (D F V B)

Ion	λ (Å) (Lab)	λ (Å) (Solar)	Int.*
Fe II	1625.909	1625.90	0.081
Fe II	1627.401	1627.37	0.16
Fe II	1629.154	1629.16	0.18
Fe II	1629.376	1629.36	B0.075
Fe II	1631.120	1631.12	0.15
Fe II	1632.668	1632.66	0.32
Fe II	1633.908	1633.90	0.82
Fe II	1634.345	1634.34	0.094
Fe II	1635.398	1635.39	0.10
Fe II	1636.321	1636.34	0.12
Fe II	1637.397	1637.40	1.0
Fe II	1639.403	1639.40	0.10
Fe II	1640.150	1640.14	0.8
He II	1640.4	1640.39#	4.8
Fe II	1641.759	1641.77	0.059
Fe II	1643.576	1643.58	0.79
C III	1645.03	1645.01	0.088
Fe II	1649.423	1649.42	0.49
Fe II	1654.26	1654.26**	0.19
Fe II	1654.476	1654.47	0.39
C I	1656.267	1656.27	0.44
C I / C I	1656.928 } 1657.008	1656.99	0.43
C I	1657.380	1657.39	0.42
C I	1657.907	1657.92	B0.41
C I	1658.122	1658.13	0.43
Fe II	1658.771	1658.77	0.81
Fe II	1659.483	1659.48	1.5
O III	1660.803	1660.81	1.2
Fe II	1661.347	1661.32	0.091
Fe II	1663.221	1663.22	0.76
O III	1666.153	1666.15	2.94
Fe II	1669.68	1669.66**	0.18
Fe II / Al II / Fe II	1670.742 } 1670.787 } 1671.010	1670.80	1.24
Fe II	1673.462	1673.46	0.31
Fe II	1674.254	1674.25	0.44
Fe II	1674.716	1674.71	0.37
Fe II	1676.853	1676.85	0.30
Fe II	1679.381	1679.39	0.28
Fe II	1681.12	1681.10	0.41
Fe II	1685.954	1685.95	0.40
Fe II	1686.455	1686.45	0.40
Fe II	1686.692	1686.68	0.47
Fe II	1688.401	1688.39	0.17
Fe II	1689.828	1689.83	0.073
Fe II	1690.759	1690.77	0.069
Fe II	1691.271	1691.27	0.47
Ni III? / Fe II	1692.514 } 1692.516	1692.52	0.059
Fe II	1693.936	1693.93	0.16
Fe II	1694.68	1694.67**	0.071
Fc II	1696.794	1696.78	0.65
Fe II	1698.190	1698.13	0.05
Fe II	1699.190	1699.19	0.059
Fe II	1702.043	1702.04	1.65
Ni II	1703.408	1703.41	0.084
Fc II	1704.652	1704.63	0.25
Fe II	1706.142	1706.14	0.26
Fe II	1707.399	1707.40	0.069
Fe II	1707.66	1707.66**	0.071
Fe II	1708.250	1708.25	0.05
Fe II	1708.621	1708.62	0.59
Ni II	1709.598	1709.59	0.52
Fe II	1712.997	1713.00	1.65
Fe II	1715.503	1715.50	0.12

Ion	λ (Å) (Lab)	λ (Å) (Solar)	Int.*
Fe II	1716.577	1716.57	0.55
Fe II	1718.123	1718.09	0.25
N IV	1718.551	1718.56	0.06?
Fe II	1720.042	1720.03	0.080
Fe II	1720.616	1720.61	1.37
Al II	1721.26	1721.27	0.091
Fe II	1722.425	1722.42	0.055
Fe II	1724.854	1724.87	0.89
Fe II	1726.391	1726.39	1.0
		1728.94	0.39
Fe II	1731.038	1731.05	0.064
Ni II	1741.547	1741.55	0.71
Fe II / N III	1746.818 } 1746.82P	1746.82	0.20
Ni II	1748.285	1748.28	0.44
N III	1748.61	1748.63	0.15
Fe II	1749.136	1749.12	0.045
N III	1749.674	1749.67	0.70
Ni II	1751.911	1751.91	0.52
N III	1752.16P	1752.12	B0.11
N III	1753.986	1753.98	0.15
Ni II	1754.808	1754.80	0.10
Fe II	1761.379	1761.36	0.21
Al II	1763.952	1763.95	0.10
Fe II	1764.117	1764.07	B
Fe II	1772.509	1772.50	0.34
Ni II	1773.949	1773.94	0.11
Fe II	1785.262	1785.27	0.059
Fe II	1788.072	1788.04	0.094
Ni II	1788.485	1788.48	0.26
Fe II	1793.367	1793.36	0.21
Fe II	1798.156	1798.15	0.12
Ni II	1804.473	1804.48	0.069
Si II	1808.012	1808.01	5.6
Si II	1816.928	1816.93	9.5
Si II	1817.451	1817.44	0.92
Fe II	1818.509	1818.51	0.10
Fe II	1822.150	1822.13	0.063
Fe II	1823.888	1823.89	0.056
Fe II	1835.874	1835.86	0.12
Fe II	1841.701	1841.65	0.081
Fe II	1846.573	1846.57	0.063
Fe II	1848.771	1848.76	0.056
Al III	1854.716	1854.72	1.4
Fe II	1859.741	1859.74	0.14
Fe II	1860.055	1860.04	0.36
Al III	1862.790	1862.79	0.70
Fe II	1864.743	1864.72	0.16
Fe II	1876.838	1876.83	0.25
Fe II	1877.467	1877.46	0.11
Fe II	1880.976	1880.97	0.081
Fe II	1888.733	1888.73	0.12
Si III	1892.030	1892.04	15.2
Fe III?	1895.457	1895.48	0.34
Fe II	1898.538	1898.54	0.050
Fe II	1901.76	1901.76**	0.088
Fe II	1904.784	1904.79	0.045
C III	1908.734P	1908.74	4.05
Fe III	1914.071	1914.07††	0.29
Fe III	1915.095	1915.09††	0.088
Fe II	1917.337	1917.31	0.053
Fe II	1925.983	1925.99	0.13
Fe III	1926.323	1926.31††	0.22
C I	1930.905	1930.91	0.55
Fe II	1935.296	1935.30	0.081
Fe II	1936.799	1936.80	0.069

NOTES TO TABLE 2

NOTE.—B = blend.   P = predicted wavelength.
* Peak intensity of the line. The units are the same as used in Table 1.

Notes to Table 2 *(DFVE)*

* The differences between our measured wavelengths and the wavelengths given in Kelly and Palumbo (1973) for these lines are considerable. We feel that the laboratory wavelengths are in error.

\+ Burton and Ridgeley (1970) identify this line as S V ($3s^2$ $^1S_0$ $-$ $3s3p$ $^3P_1$). However, the limb brightening curve for this line is suggestive of a lower temperature ion.

**The wavelength difference between the laboratory and solar wavelength is considerable, and the difference is unexplained.

*+We tentatively identify these weak lines as transitions in phosphorus ions.

++The 1640.39 Å He II line is actually composed of seven components, e.g., see Feldman et al. (1975b).

‡ Int ≡ photographic density measured by a densitometer. Values near 90 correspond to saturated lines.

B = blend

E.2 The Long Wavelength Spectra

E.2.1 (DFC) "Chromospheric Limb Spectra from Skylab: 2000 to 3200 A," G. A. Doschek, U. Feldman and L. Cohen. Ap. J. Supp. Series 33, 101, 1977.

λ (Å) Solar (air)	λ (Å) Lab	Ion	Mul*	Flux† π(photons cm⁻² s⁻¹ sr⁻¹)
1986.88	0.907	Fe III	(50)	...
1991.03	0.016	Fe III	(50)	...
2000.36	0.368	Fe II	(122)	7.4(13)
2010.69	0.688	Fe II	(122)	4.1(13)
2015.48	0.500	Fe II	(83)	4.3(13)
2018.78	0.772	Fe II	(94)	1.0(14)
2020.75	0.739	Fe II	(83)	5.5(13)
2025.53	0.58	Cr II	(2)	3.7(13)
2029.20	0.182	Fe II	(93)	2.2(13)
2032.40	0.407	Fe II	(94)	8.8(13)
2036.44	0.435	Fe II	(137)	3.2(13)
2039.90	0.90	Cr II	(2)	2.4(13)
2040.68	0.687	Fe II	(93)	1.9(14)
2051.04	0.028	Fe II	(93)	1.1(14)
2055.59	0.59	Cr II	(1)	1.8(14)
2057.34	0.332	Fe II	(82)	2.0(13)
2061.58	{ 0.54 / 0.552	Cr II / Fe III	(1) / (48)	1.5(14) / ...
2062.00	0.00	Fe II‡	...	2.7(13)
2063.69	0.672	Fe II	(92)	6.5(13)
2065.50	0.460	Cr II	(1)	1.2(14)
2067.96	0.917	Fe II	(137)	3.0(13)
2068.24	0.243	Fe III	(48)	1.9(13)
2079.00	0.989	Fe III	(48)	2.6(13)
2080.25	0.246	Fe II	(92)	4.6(13)
2087.56	0.527	Fe II	(108)	2.1(13)
2090.14	0.14	Ni II	(15)	7.9(12)
2093.53	0.55	Ni II	(15)	9.7(12)
2097.10	0.08	Ni II	(31)	1.1(13)
2097.57	0.512	Fe II	{(80) / (120)}	1.6(13)
2103.85	0.799	Fe III	(66)	...
2107.41	0.324	Fe III	(66)	...
2108.00	{ 7.94 / 0.139	Ni II / Fe II	(60) / (81)	1.0(13)
2110.74	0.724	Fe II	(108)	1.4(13)
2118.17	0.195	Fe II	(120)	8.3(12)
2119.03	0.050	Fe II	(120)	1.0(13)
2125.14	0.12	Ni II	(14)	1.0(13)
2128.58	0.57	Ni II	(15)	2.0(13)
2130.24	0.259	Fe II	(80)	1.2(13)
2131.28	0.27	Ni II	(14)	7.9(12)
2132.67	0.72	Cr II	(24)	7.9(12)
2133.50	0.49	Cr II	(23)	1.6(13)
2134.56	{ 0.52 / 0.62	Cr II / Cr II	(23) / (23)	1.6(13)
2135.37	0.34	Cr II	(23)	1.2(13)
2137.71	0.735	Fe II	(6)	7.4(12)
2138.61	0.60	Ni II	(13)	1.2(13)
2139.01	...	...	...	2.6(13)
2139.62	0.676	Fe II	(6)	1.1(13)
2142.77	...	...	...	6.0(13)
2146.05	0.058	Fe II	(6)	1.2(13)
2147.68	0.719	Fe II	(213)	...
2150.65	{ 0.618 / 0.762	Fe II / Fe II	(135) / (248)	1.5(13)
2151.10	0.095	Fe II	(106)	1.2(13)
2152.38	{ 0.373 / 0.488	Fe II / Fe II	(106) / (151)	1.4(13)
2158.75	0.73	Ni II	(13)	1.3(13)
2161.21	{ 0.161 / 0.21	Fe II / Ni II	(213) / (14)	... / 2.8(13)
2162.01	0.023	Fe II	(90)	1.2(14)
2164.34	0.339	Fe II	(79)	2.7(13)
2165.55	{ 0.555 / 0.55	Fe II / Ni II	(185) / (13)	1.3(14)
2169.10	0.10	Ni II	(13)	7.9(13)
2172.95	0.989	Fe II	(134)	6.9(12)
2174.68	0.67	Ni II	(14)	9.2(13)
2175.15	0.16	Ni II	(13)	7.4(13)
2175.42	0.445	Fe II	(90)	7.4(13)
2177.06	{ 0.025 / 0.080	Fe II / Ni II	(106) / (40)	1.3(13)
2179.37	0.36	Ni II	(40)	9.7(12)
2180.48	0.46	Ni II	(40)	1.5(13)
2184.60	0.61	Ni II	(13)	6.9(13)
2185.51	0.51	Ni II	(40)	2.2(13)
2186.84	0.89	Fe II‡	...	9.7(12)
2187.71	0.678	Fe II?	(89)	1.2(13)
2188.02	0.05	Ni II	(12)	6.9(12)
2189.03	8.999	Co II	(11)	1.1(13)
2192.31	0.26	Cu II	(14)	9.2(12)
2201.41	0.41	Ni II	(13)	5.5(13)
2206.71	0.71	Ni II	(13)	8.3(13)
2210.38	0.38	Ni II	(13)	5.1(13)
2211.08	{ 0.952 / 0.090 / 0.112	Fe II / Ni II / Fe II	(118) / (52) / {(168) / (289)}	6.9(12)
2213.22	0.19	Ni II	(30)	9.7(12)
2213.65	0.679	Fe II	(168)	4.2(13)
2216.48	0.479	Ni II	(12)	1.3(14)
2219.90	0.889	Fe II	(168)	2.8(13)
2220.38	{ 0.388 / 0.40	Fe II / Ni II	(118) / (28)	1.1(14)
2221.16	0.160	Fe II	(168)	2.2(13)
2222.96	0.948	Ni II	(12)	9.7(13)
2223.48	0.481	Fe II	(168)	2.1(13)
2224.40	0.351	Ni II	(21)	1.7(13)
2224.86	0.88	Ni II	(12)	1.1(14)
2226.33	0.34	Ni II	(12)	8.8(13)
2227.22	0.18	Fe II‡	...	7.9(12)
2229.88	0.85	Ni II§	...	...
2232.08	0.05	Co II	(10)	2.3(13)
2233.91	0.917	Fe II	(118)	8.3(13)
2236.66	0.680	Fe II	(4)	7.9(12)
2240.34	0.33	Fe II‡	...	9.7(12)
2241.78	0.81	Fe II‡	...	7.9(12)
2243.59	0.578	Fe II	(118)	8.3(12)
2244.03	...	...	...	...
2244.65	0.60	Fe II‡	...	1.2(13)
2245.13	0.11	Co II	(10)	1.8(13)
2246.93	0.995	Cu II	(13)	4.2(13)
2249.17	0.18	Fe II	(5)	1.4(14)
2250.17	0.171	Fe II	(4)	5.5(13)
2250.93	0.937	Fe II	(4)	9.2(13)
2251.55	0.556	Fe II	(5)	3.8(13)
2253.13	0.119	Fe II	(4)	1.4(14)
2254.37	0.401	Fe II	(5)	1.2(13)
2255.14	0.16	Fe II‡	...	1.6(13)
2255.77	0.759	Fe II	(133)	6.5(13)
2255.94	0.979	Fe II	(4)	BL
2256.43	0.43	Fe II‡	...	2.2(13)
2257.91	0.96	...	...	7.4(12)
2260.11	{ 0.078 / 0.228	Fe II / Fe II	(4) / (5)	2.0(14)
2260.85	0.853	Fe II	(4)	6.9(13)
2262.68	0.686	Fe II	(5)	4.6(13)
2263.21	0.224	Fe II	(246)	1.2(13)
2264.47	0.456	Ni II	(12)	1.2(14)
2265.99	0.991	Fe II	(5)	4.3(13)
2267.58	0.584	Fe II	(4)	1.4(14)
2268.11	0.14	Fe II‡	...	1.0(13)
2268.58	0.562	Fe II	(5)	2.1(13)
2268.76	0.844	Fe II	(5)	1.5(13)
2270.21	0.209	Ni II	(12)	1.2(14)
2274.73	0.75	Ni II	(38)	6.9(12)
2275.68	0.70	Ni II	(39)	1.1(13)
2276.03	0.02	Fe II‡	...	1.4(13)
2277.28	0.282	Ni II§	...	3.6(13)
2278.76	0.771	Ni II	(22)	1.4(14)
2279.91	0.918	Fe II	(4)	2.6(14)

TABLE 1—Continued (DF^c)

λ (Å) Solar (air)	λ (Å) Lab	Ion	Mul*	Flux† π(photons cm⁻² s⁻¹ sr⁻¹)
2283.99.....	0.991	Fe II	(132)	4.0(13)
2286.14.....	0.165	Co II	(9)	4.6(13)
2287.08.....	0.08	Ni II	(22)	6.9(13)
2287.61.....	0.66	Ni II	(38)	1.2(13)
2293.76.....	0.765	Fe II	(184)	1.2(13)
2294.60.....	0.605	Fe II	(184)	1.3(13)
2296.58.....	0.55	Ni II	(21)	1.7(14)
2297.12.....	{0.140	Ni II	(11)	2.3(14)
	0.17	Cr II	(19)	
2297.44.....	0.486	Ni II	(11)	1.4(14)
2298.26.....	{0.225	Fe II	(133)	8.8(13)
	0.269	Ni II	(21)	
2298.91.....	0.95	Mn II	(2)	9.2(12)
2299.64.....	0.65	Ni II	(27)	2.6(13)
2300.07.....	0.10	Ni II	(27)	3.0(13)
2301.38.....	0.424	Fe II	(184)	8.3(12)
2302.48.....	0.465	Ni II	(59)	1.4(13)
2302.99.....	0.98	Ni II	(11)	2.1(14)
2303.23.....	0.238	V II?	(26)	BL
2304.75.....	0.736	Fe II	(184)	1.5(13)
2304.95.....	5.001	Mn II	(2)	1.5(13)
2307.15.....	0.19	Cr II	(19)	2.3(13)
2307.84.....	0.84	Co II	(9)	5.1(13)
2311.23.....	0.224	Fe II	(245)	1.1(13)
2311.61.....	0.602	Co II	(9)	4.6(13)
2312.02.....	0.028	Fe II	(105)	4.6(13)
2312.91.....	0.91	Ni II	(58)	2.4(13)
2314.04.....	0.036	Co II	(9)	2.1(13)
2314.75.....	{0.71	Cr II	(19)	1.8(13)
	0.81	Cr II	(19)	...
2314.93.....	0.97	Co II	(9)	2.8(13)
2316.04.....	0.034	Ni II	(11)	3.3(14)
2318.52.....	0.534	Fe II	(132)	3.3(13)
2319.36.....	0.38	Cr II?	(34)	1.8(13)
2319.74.....	0.73	Ni II	(37)	9.2(12)
2320.06.....	0.08	Cr II	(11)	1.4(13)
2321.68.....	0.687	Fe II	(183)	1.3(13)
2322.34.....	0.326	Fe II	(183)	1.0(13)
2323.52.....	0.500	C II§	(0.01)	1.5(13)
2324.39.....	0.317	Co II	(8)	...
2324.72.....	0.689	C II§	(0.01)	1.9(14)
2325.40.....	0.398	C II§	(0.01)	3.8(14)
2326.16.....	0.15	Co II	(8)	...
2326.46.....	{0.44	Ni II	(11)	4.2(13)
	0.493	Co II	(8)	
2326.98.....	0.930	C II§	(0.01)	5.7(13)
2327.39.....	0.391	Fe II	(2)	4.6(14)
2328.14.....	0.122	C II§	(0.01)	2.2(14)
2330.35.....	0.37	Co II	(8)	1.6(13)
2331.30.....	0.308	Fe II	(35)	4.6(14)
2332.81.....	0.798	Fe II	(3)	5.1(14)
2334.55.....	{0.590	Ni II	(20)	...
	0.606	Si II	(0.01)	5.5(14)
2335.44.....	0.42	Fe II‡	...	...
2336.21.....	0.246	Co II	(8)	1.4(13)
2336.70.....	0.70	Ni II	(50)	1.7(13)
2338.01.....	0.005	Fe II	(3)	5.1(14)
2339.40.....	0.408	Fe II	(105)	7.4(13)
2340.46.....	0.459	Fe II	(166)	3.9(13)
2341.12.....	{0.939	Fe II	(166)	...
	1.18	Ni II	(50)	2.9(13)
2342.22.....	0.238	Fe II	(104)	3.0(13)
2343.41.....	0.495	Fe II	(3)	5.5(14)
2343.90.....	0.958	Fe II	(35)	5.5(14)
2344.24.....	0.278	Fe II	(3)	5.5(14)
2345.34.....	0.327	Fe II	(165)	1.2(14)
2347.40.....	0.406	Co II	(8)	2.0(13)
2348.21.....	{0.118	Fe II	(36)	6.5(14)
	0.300	Fe II	(3)	...
2350.17.....	0.174	Si II	(0.01)	2.5(14)
2351.19.....	0.198	Fe II	(165)	1.0(14)
2352.09.....	...	...	...	...

λ (Å) Solar (air)	λ (Å) Lab	Ion	Mul*	Flux† π(photons cm⁻² s⁻¹ sr⁻¹)
2352.69.....	....	...	...	...
2353.42.....	0.446	Co II	(8)	2.6(13)
2354.50.....	0.473	Fe II	(165)	1.0(14)
2354.90.....:	0.884	Fe II	(35)	3.9(14)
2356.40.....	0.41	Ni II	(22)	2.5(13)
2357.00.....	0.005	Fe II	(333)	1.6(13)
2359.12.....	0.111	Fe II	(3)	4.8(14)
2359.97.....	0.999	Fe II	{(35)	6.5(14)
			(165)	
2360.28.....	0.287	Fe II	(36)	6.5(14)
2362.00.....	0.014	Fe II	(35)	3.3(14)
2363.80.....	0.838	Co II	(8)	5.9(13)
2364.83.....	0.825	Fe II	(3)	5.2(14)
2366.61.....	0.591	Fe II	(35)	2.8(14)
2367.38.....	0.395	Ni II	(11)	2.7(13)
2368.60.....	0.593	Fe II	(36)	5.2(14)
2369.19.....	0.232	Fe II	(182)	2.5(13)
2370.50.....	0.494	Fe II	(35)	3.1(14)
2372.63.....	0.631	Fe II	(333)	1.8(13)
2373.74.....	0.733	Fe II	(2)	4.8(14)
2375.23.....	0.192	Fe II	(36)	5.2(14)
2378.61.....	0.636	Co II	(7)	4.8(13)
2379.26.....	0.275	Fe II	(36)	4.3(14)
2380.77.....	0.757	Fe II	(3)	3.7(14)
2382.08.....	0.034	Fe II	(2)	1.0(15)
2383.15.....	{0.060	Fe II	(2)	9.6(14)
	0.242	Fe II	(36)	
2384.40.....	0.386	Fe II	(36)	4.8(14)
2384.99.....	0.999	Fe II	(35)	1.4(14)
2386.35.....	0.367	Co II	(7)	3.2(13)
2387.43.....	0.424	Fe II	(286)	1.6(13)
2387.77.....	0.77	Ni II	(19)	2.2(13)
2388.58.....	0.629	Fe II	(2)	4.2(14)
2389.53.....	0.565	Co II	(7)	1.6(13)
2391.47.....	0.475	Fe II	(35)	2.2(14)
2394.53.....	0.518	Ni II	(20)	1.8(14)
2394.85.....	{0.892	Fe II	(116)	8.6(13)
	0.843	Ni II	(36)	BL
2395.59.....	{0.416	Fe II	(2)	5.2(14)BL
	0.627	Fe II	(2)	5.2(14)
2395.71.....	0.714	Fe II	(211)	4.4(13)
2397.39.....	0.423	Co II?	(16)	2.1(13)
2399.25.....	0.237	Fe II	{(2)	4.3(14)
			(36)	
2400.33.....	{0.274	Fe II	(181)	1.7(14)
	0.338	Fe II	(244)	
2402.28.....	0.255	Fe II	(181)	...
2402.59.....	0.597	Fe II	(36)	1.6(14)
2404.40.....	0.430	Fe II	(2)	2.8(14)
2404.90.....	0.882	Fe II	(2)	4.7(14)
2406.68.....	0.660	Fe II	(2)	4.7(14)
2407.92.....	0.940	Fe II	(116)	5.0(13)
2408.73.....	0.770	Co II	(7)	1.8(13)
2409.37.....	0.377	Fe II	(150)	1.3(13)
2409.70.....	0.708	Fe II	(224)	1.5(13)
2410.54.....	0.521	Fe II	(2)	4.3(14)
2411.05.....	0.062	Fe II	(2)	4.0(14)
2413.32.....	0.308	Fe II	(2)	4.3(14)
2414.08.....	{0.069	Co II	(7)	2.4(13)
	0.080	Fe II	(164)	
2415.06.....	0.068	Fe II	(181)	5.3(13)
2416.14.....	0.134	Ni II	(20)	2.5(14)
2416.82.....	0.705	Fe II	(286)	1.5(13)
2417.85.....	0.859	Fe II	(244)	2.2(14)
2420.74.....	0.735	Co II	?	1.1(13)
2421.92.....	0.898	Fe II	(116)	1.3(13)
2422.70.....	0.688	Fe II	(301)	5.0(13)
2423.20.....	0.204	Fe II	(301)	3.3(13)
2424.16.....	0.141	Fe II	(180)	...
2424.47.....	{0.380	Fe II	(149)	2.6(14)
	0.585	Fe II	(180)	
2425.36.....	0.362	Fe II	(210)	1.7(13)

TABLE 1—*Continued* (T) F<)

λ (Å) Solar (air)	λ (Å) Lab	Ion	Mul*	Flux† π(photons cm⁻² s⁻¹ sr⁻¹)
2425.72.....	0.677	Fe II	(224)	2.4(13)
2427.18.....	0.197	Fe II	(114)	1.6(13)
2428.34.....	0.367	Fe II	(300)	7.9(13)
2429.40.....	{0.382	Fe II	(148)}	7.2(13)
	{0.497	Fe II	(180)}	
2430.09.....	0.073	Fe II	(180)	2.8(14)
2432.26.....	0.259	Fe II	(180)	2.3(14)
2433.50.....	{0.495	Fe II	(164)}	1.1(14)
	{0.57	Ni II	(19)}	...
2434.85.....	{0.733	Fe II	(321)}	1.4(14)
	{0.942	Fe II	(180)}	
2435.80.....	0.816	Fe II	(164)	1.5(13)
2436.20.....	0.222	Fe II	(209)	1.8(13)
2437.18.....	0.157	Fe II	(210)	2.0(13)
2437.89.....	0.892	Ni II	(19)	8.6(13)
2439.30.....	0.301	Fe II	(209)	3.0(14)
2440.42.....	0.416	Fe II	(300)	4.2(13)
2444.52.....	0.515	Fe II	(148)	4.0(14)
2445.58.....	0.569	Fe II	(148)	3.3(14)
2446.16.....	0.203	Fe II	(209)}	2.0(14)
2446.47.....	0.462	Fe II	(164)}	
2447.25.....	{0.203	Fe II	(300)}	4.4(13)
	{0.320	Fe II	(299)}	
2447.74.....	0.753	Fe II	(320)	4.0(13)
2449.20.....	0.185	Fe II	(129)	1.5(13)
2449.75.....	0.739	Fe II	(34)}	6.0(13)
2450.04.....	{9.961	Fe II	(300)}	
	{0.022	Co II?	(16)}	
2451.14.....	{0.106	Fe II	(34)}	5.7(13)
	{0.208	Fe II	(209)}	...
2453.79.....	0.794	Fe II	(163)	8.6(13)
2454.57.....	0.574	Fe II	(320)	5.7(13)
2456.81.....	0.816	Fe II	(209)	1.9(13)
2458.79.....	0.782	Fe II	(209)}	2.9(14)
2458.99.....	{0.964	Fe II	(299)}	
	{9.097	Fe II	(163)}	
2461.29.....	0.282	Fe II	(209)	1.9(14)
2461.83.....	0.855	Fe II	(209)	2.6(14)
2463.29.....	0.280	Fe II	(208)	8.1(13)
2464.01.....	0.007	Fe II	(208)	1.0(14)
2464.96.....	0.903	Fe II	(208)	1.1(14)
2465.15.....	0.194	Fe II	(148)	1.2(14)
2465.91.....	0.911	Fe II	(208)	1.0(14)
2466.76.....	{0.670	Fe II	(179)}	1.6(14)
	{0.811	Fe II	(179)}	
2468.29.....	0.292	Fe II	{(145)(163)}	9.0(13) ...
2469.49.....	0.512	Fe II	(299)	5.2(13)
2470.47.....	0.406	Fe II	(208)}	2.3(14)
2470.68.....	{0.661	Fe II	(179)}	
	{0.752	Fe II	(223)}	
2472.10.....	0.075	Fe II	(162)	2.1(13)
2472.42.....	0.426	Fe II	(179)	6.0(13)
2472.91.....	0.910	Fe I	(9)	...
2473.30.....	0.314	Fe II	(148)	8.5(13)
2474.75.....	0.762	Fe II	(208)	7.1(13)
2476.26.....	0.264	Fe II	(163)	8.2(13)
2476.66.....	...	...	...	4.8(13)
2477.35.....	0.342	Fe II	(162)	6.0(13)
2478.19.....	{0.115	Fe II	(224)}	1.8(14)
	{0.206	Fe II	(149)}	
2478.56.....	{0.449	Fe II	(161)}	
	{0.568	Fe II	(179)}	
2479.86.....	0.775	Fe I	(9)}	2.6(14)
2480.15.....	0.155	Fe II	(179)}	
2481.04.....	0.044	Fe II	(243)	3.5(13)
2482.12.....	0.117	Fe II	(161)	2.8(14)
2482.64.....	0.654	Fe II	(207)	1.4(14)
2483.25.....	0.270	Fe I	(9)	3.2(13)
2483.73.....	0.721	Fe II	(331)	1.8(13)
2484.23.....	0.243	Fe II	(243)	1.8(14)
2485.04.....	0.076	Fe II	(34)	2.0(13)
2486.35.....	0.343	Fe II	(208)	1.8(14)
2488.14.....	0.143	Fe I	(9)	3.4(13)
2489.51.....	0.485	Fe II	(161)	1.8(14)
2489.81.....	0.826	Fe II	(207)	2.8(14)
2490.84.....	0.856	Fe II	(179)	1.7(14)
2491.38.....	0.392	Fe II	(207)	9.6(13)
2492.35.....	0.341	Fe II	(243)	4.0(13)
2493.25.....	{0.174	Fe II	{(161)(207)}}	8.5(14)
	{0.269	Fe II	(161)}	
2494.11.....	0.111	Fe II	(161)	2.5(13)
2497.80.....	{0.709	Fe II	(242)}	...
	{0.817	Fe II	{(175)(207)}}	1.4(14)
2498.90.....	0.897	Fe II	(161)	4.5(14)
2500.93.....	0.919	Fe II	(357)	2.7(13)
2502.39.....	0.388	Fe II	(207)	1.3(14)
2503.38.....	{0.323	Fe II	(206)}	2.4(14)
	{0.560	Fe II	{(161)(175)}}	...
2503.82.....	0.870	Fe II	(285)	1.2(14)
2505.21.....	0.217	Fe II	(33)	4.6(13)
2506.09.....	0.091	Fe II	(207)	1.0(14)
2506.38.....	0.429	Fe II	(128)	3.4(13)
2506.94.....	0.896	Si I	(1)	1.8(13)
2509.12.....	0.117	Fe II	(242)	3.1(13)
2510.88.....	0.87	Ni II	(18)	9.5(13)
2511.44.....	0.375	Fe II	(33)	...
2511.77.....	0.759	Fe II	(161)	6.8(14)
2512.52.....	0.513	Fe II	(343)	2.4(13)
2514.38.....	0.383	Fe II	(285)	8.8(13)
2514.91.....	0.912	Fe II	{(175)(206)}	5.0(13)
2516.10.....	0.108	Si I	(1)	2.6(13)
2517.13.....	0.124	Fe II	(147)	2.0(14)
2518.08.....	0.100	Fe I	(7)	1.4(13)
2519.05.....	0.044	Fe II	(268)	1.1(14)
2519.80.....	0.829	Co II?	(15)	1.8(13)
2520.67.....	0.669	Fe II	(242)	2.1(13)
2521.09.....	0.089	Fe II	(268)	7.4(13)
2521.82.....	0.810	Fe II	(330)	4.8(13)
2522.18.....	0.189	Fe II	(159)	3.5(13)
2522.86.....	0.848	Fe I	(7)	5.7(13)
2524.15.....	0.108	Si I	(1)	1.3(13)
2525.41.....	0.386	Fe II	(159)	5.1(14)
2526.22.....	{0.071	Fe II	(159)}	3.7(14)
	{0.292	Fe II	(145)}	
2527.11.....	0.107	Fe II	(159)	1.4(14)
2527.43.....	0.433	Fe I	(7)	6.7(13)
2528.59.....	0.51	Si I	(1)	3.2(13)
2529.24.....	0.221	Fe II	(241)	...
2529.55.....	0.545	Fe II	{(145)(175)}	5.3(14)
2530.09.....	0.103	Fe II	(178)	2.3(14)
2531.20.....	{0.082	Fe II	(33)}	4.5(13)
	{0.266	Ti II?	(4)}	
2532.68.....	...	...	...	1.6(13)
2533.64.....	0.626	Fe II	(159)	7.5(14)
2534.41.....	0.413	Fe II	(159)	6.0(14)
2535.47.....	0.480	Fe II	(177)}	2.6(14)
2535.75.....	0.880	Ti II?	(4)}	
2536.81.....	{0.673	Fe II	(241)}	6.0(14)
	{0.882	Fe II	(159)}	
2538.32.....	{0.205	Fe II	(319)}	2.9(14)
	{0.500	Fe II	(160)}	
2538.95.....	{0.794	Fe II	(158)}	6.5(14)
	{0.898	Fe II	(158)}	
	{9.003	Fe II	(158)}	
2540.67.....	0.669	Fe II	{(177)(343)}	9.0(13)
2541.08.....	0.094	Fe II	(177)	1.6(14)
2541.83.....	0.831	Fe II	(158)	3.3(14)

TABLE 1—*Continued* (DFc)

λ (Å) Solar (air)	λ (Å) Lab	Ion	Mul*	Flux† π(photons cm⁻² s⁻¹ sr⁻¹)
2542.74.....	0.733	Fe II	(223)	5.4(13)
2543.38.....	{0.382	Fe II	(159)	3.8(14)
	0.431	Fe II	(177)	...
2545.15.....	{4.992	Fe II	(147)	
	0.215	Fe II	(159)	3.2(14)
2545.87.....	0.903	Ni II	(18)	3.5(13)
2546.67.....	0.667	Fe II	(177)	2.8(14)
2547.32.....	0.330	Fe II	(158)	6.6(13)
2548.37.....	0.325	Fe II	(146)	8.7(13)
2548.72.....	0.741	Fe II	(145)	2.3(14)
2549.40.....	{0.399	Fe II	(177)	3.1(14)
	0.453	Fe II	(177)	
2550.02.....	0.023	Fe II	(240)	4.0(14)
2550.67.....	{0.575	Fe II	(158)	...
	0.680	Fe II	(240)	3.4(14)
2553.71.....	0.738	Fe II	(127)	2.7(13)
2555.06.....	0.066	Fe II	(177)	8.5(13)
2555.42.....	0.447	Fe II	(177)	5.6(13)
2555.96.....	0.988	Ti II?	(9)	2.2(13)
2557.52.....	0.500	Fe II	(175)	9.9(13)
2558.60.....	0.605	Mn II	(20)	4.6(13)
2559.80.....	0.774	Fe II	(205)	1.1(14)
2560.26.....	0.278	Fe II	(221)	2.5(14)
2562.16...:..	0.094	Fe II	(221)	
2562.54.....	0.535	Fe II	(64)	1.9(15)
2563.48.....	0.472	Fe II	(64)	1.2(15)
2566.26.....	...	...	...	5.6(13)
2566.91.....	0.908	Fe II	(64)	1.2(15)
2567.51.....	...	...	...	2.2(13)
2568.39.....	0.405	Fe II	(145)	1.0(14)
2569.76.....	0.775	Fe II	(266)	2.3(13)
2570.84.....	0.843	Fe II	(284)	1.5(14)
2571.50.....	0.542	Fe II?	(174)	3.1(13)
2571.90.....	0.78	Cr II	(89)	2.4(13)
2572.58.....	...	...	...	1.6(13)
2573.20.....	0.206	Fe II	(205)	8.6(13)
2574.36.....	0.363	Fe II	(144)	6.0(14)
2576.11.....	0.107	Mn II	(1)	6.5(14)
2576.87.....	0.859	Fe II	(326)	7.5(13)
2577.92.....	0.920	Fe II	(64)	1.0(15)
2579.42.....	0.406	Fe II	(266)	4.4(13)
2580.30.....	0.372	Co II?	(14)	9.5(13)
2581.32.....	...	...	...	2.6(13)
2582.59.....	0.582	Fe II	(64)	9.4(14)
2585.88.....	0.876	Fe II	(1)	2.5(15)
2587.19.....	0.225	Co II	...	3.0(13)
2587.94.....	0.945	Fe II	(326)	8.5(13)
2590.59.....	0.548	Fe II	(145)	4.7(13)
2591.55.....	0.542	Fe II	(64)	1.2(15)
2592.77.....	0.781	Fe II	(318)	4.4(14)
2593.72.....	{0.722	Fe II	(64)	8.8(14)
	0.731	Mn II	(1)	
2595.21.....	0.285	Fe II	(172)	2.6(13)
2598.39.....	0.369	Fe II	(1)	>2.5(15)
2599.40.....	0.395	Fe II	(1)	>2.5(15)
2605.63.....	0.697	Mn II	(1)	6.5(14)
2606.56.....	0.514	Fe II	(342)	...
2607.01.....	0.084	Fe II	(1)	>2.5(15)
2608.86.....	0.852	Fe II	(171)	...
2609.07.....	0.122	Fe II	(310)	3.9(13)
2609.87.....	0.859	Fe II	(204)	7.1(13)
2610.16.....	0.202	Mn II	(19)	7.5(13)
2611.08.....	0.075	Fe II	(64)	3.0(14)
2611.88.....	0.873	Fe II	(1)	>2.5(15)
2613.83.....	0.820	Fe II	(1)	>2.5(15)
2617.62.....	0.618	Fe II	(1)	>2.5(15)
2619.07.....	0.071	Fe II	(171)	1.0(14)
2620.45.....	{0.408	Fe II	(1)	3.2(14)
	0.693	Fe II	(171)	...
2621.66.....	0.669	Fe II	(1)	8.0(14)
2623.11.....	0.129	Fe II	(318)	2.6(13)

λ (Å) Solar (air)	λ (Å) Lab	Ion	Mul*	Flux† π(photons cm⁻² s⁻¹ sr⁻¹)
2623.74.....	0.721	Fe II	(171)	8.0(13)
2625.66.....	{0.489	Fe II	(318)	...
	0.664	Fe II	(1)	1.6(15)
2626.46.....	0.499	Fe II	(173)	1.5(14)
2628.30.....	0.291	Fe II	(1)	1.5(15)
2629.58.....	0.590	Fe II	(171)	2.4(14)
2630.05.....	0.068	Fe II	(171)	1.8(14)
2631.21.....	{0.045	Fe II	(1)	3.9(15)
	0.321	Fe II	(171), (1)	
2632.31.....	0.353	Mn II	(19)	4.7(13)
2633.20.....	0.200	Fe II	(356)	3.2(13)
2637.62.....	0.643	Fe II	(221)	1.1(14)
2638.13.....	0.173	Mn II	(19)	7.6(13)
2639.60.....	0.560	Fe II	(221)	6.9(13)
2641.98.....	2.015	Fe II	(309)	4.3(13)
2653.56.....	0.57	Cr II	(8)	1.8(14)
2658.58.....	0.59	Cr II	(8)	2.3(14)
2661.70.....	0.73	Cr II	(8)	7.4(13)
2663.49.....	0.42	Cr II	(8)	1.6(14)
2664.66.....	0.665	Fe II	(263)	7.0(14)
2666.00.....	0.02	Cr II	(8)	2.8(14)
2666.63.....	0.631	Fe II	(203)	5.0(14)
2668.70.....	0.71	Cr II	(8)	2.9(14)
2669.14.....	0.17	Al II	(1)	7.1(14)
2671.78.....	0.80	Cr II	(8)	3.9(14)
2672.80.....	0.83	Cr II	(8)	2.8(14)
2677.15.....	{0.13	Cr II	(8)	7.6(14)
	0.19	Cr II	(8)	
2678.77.....	0.79	Cr II	(7)	4.3(14)
2684.73.....	0.752	Fe II	(282)	2.8(14)
2687.06.....	0.09	Cr II	(7)	2.3(14)
2687.94.....	0.960	V II?	(3)	5.3(13)
2688.20.....	0.28	Cr II	(84)	4.9(13)
2689.15.....	0.20	Cr II	(35)	3.2(13)
2691.02.....	0.03	Cr II	(8)	1.6(14)
2692.63.....	0.601	Fe II	(283)	3.2(14)
2697.44.....	{0.330	Fe II	(341)	5.5(13)
	0.453	Fe II	(341)	
2698.52.....	0.40	Cr II	(7)	3.6(14)
2701.67.....	0.693	Mn II	(18)	1.1(14)
2703.98.....	0.988	Fe II	(261)	4.3(14)
2705.70.....	0.727	Mn II	(18)	1.0(14)
2708.40.....	0.445	Mn II	(18)	7.5(13)
2709.06.....	0.051	Fe II	(218)	1.1(14)
2710.28.....	0.332	Mn II	(18)	5.5(13)
2711.84.....	0.842	Fe II	(201)	2.9(14)
2712.31.....	0.300	Cr II	(7)	2.2(14)
2714.41.....	0.414	Fe II	(63)	1.1(15)
2716.21.....	0.216	Fe II	(261)	3.2(14)
2717.51.....	{0.51	Cr II	(7)	8.1(13)
	0.533	Fe II	(32)	
2718.99.....	9.027	Fe II	(5)	4.2(13)
2722.72.....	0.74	Cr II	(7)	1.6(14)
2724.86.....	0.879	Fe II	(62)	3.8(14)
2726.47.....	0.509	Fe II	(261)	...
2727.50.....	{0.382	Fe II	(200)	...
	0.538	Fe II	(63)	1.2(15)
2730.72.....	0.735	Fe II	(62)	5.9(14)
2732.41.....	0.441	Fe II	(32)	7.6(13)
2736.96.....	0.968	Fe II	(63)	1.1(15)
2739.56.....	0.545	Fe II	(63)	2.3(15)
2741.37.....	0.395	Fe II	(260)	4.3(13)
2742.00.....	0.02	Cr II	(6)	6.6(13)
2743.22.....	0.196	Fe II	(62)	1.9(15)
2746.42.....	0.487	Fe II	(62)	1.9(15)
2747.03.....	6.978	Fe II	(63)	1.7(15)
2749.30.....	{0.178	Fe II	(63)	2.0(15)
	0.324	Fe II	(62)	
	0.482	Fe II	(63)	
2750.70.....	0.72	Cr II	(6)	1.8(14)

TABLE 1—*Continued* (*Ð FC*)

λ(Å) Solar (air)	λ(Å) Lab	Ion	Mul*	Flux† π(photons cm⁻² s⁻¹ sr⁻¹)
2751.07.....	0.121	Fe II	(217)	1.0(14)
2751.85.....	0.85	Cr II	(6)	1.2(14)
2753.27.....	0.289	Fe II	(235)	1.1(15)
2755.74.....	0.733	Fe II	(62)	2.3(15)
2756.97.....	7.029	Fe II	(199)	4.0(13)
2757.69.....	0.72	Cr II	(6)	1.3(14)
2759.29.....	0.336	Fe II	(32)	6.4(13)
2761.79.....	0.813	Fe II	(63)	4.0(14)
2762.56.....	0.58	Cr II	(6)	2.1(14)
2766.52.....	0.55	Cr II	(6)	3.4(14)
2767.50.....	0.50	Fe II	(235)	9.9(14)
2768.93.....	0.940	Fe II	(63)	2.1(14)
2769.26.....	{0.153 / 0.354}	Fe II / Fe II	(200) / (198)	1.3(14)
2774.62.....	0.686	Fe II	(218)	4.7(13)
2779.29.....	0.302	Fe II	(234)	3.9(14)
2779.78.....	0.832	Mg I?	(6)	7.7(13)
2783.68.....	0.690	Fe II	(234)	5.8(14)
2790.75.....	{0.768 / 0.752}	Mg II / Fe II?	(3) / (32)	1.5(14)
2793.90.....	0.887	Fe II	(198)	5.1(13)
2795.55.....	0.523	Mg II	(1)	S
2797.96.....	{0.914 / 0.989}	Fe II / Mg II	(234) / (3)	2.4(14)
2799.29.....	0.292	Fe II	(233)	5.4(13)
2802.72.....	0.698	Mg II	(1)	S
2818.30.....	...	...	...	3.7(13)
2822.34.....	0.38	Cr II	(82)	7.9(13)
2828.60.....	0.622	Fe II	(231)	4.9(13)
2830.45.....	0.46	Cr II	(82)	8.5(13)
2831.54.....	0.562	Fe II	(217)	2.9(14)
2835.64.....	0.630	Cr II	(5)	4.5(14)
2839.99.....	4.01	Cr II	(82)	7.1(13)
2840.64.....	0.644	Fe II	(217)	1.5(14)
2843.24.....	0.24	Cr II	(5)	4.8(14)
2848.03.....	0.046	Fe II	(196)	4.9(13)
2849.81.....	0.83	Cr II	(5)	4.0(14)
2852.11.....	0.120	Mg I	(1)	3.4(14)
2855.67.....	{0.67 / 0.676}	Cr II / Fe II	(5) / (196)	3.8(14)
2856.74.....	0.77	Cr II	(11)	7.6(13)
2857.37.....	0.40	Cr II	(11)	6.3(13)
2858.36.....	0.340	Fe II	{(195) / (279)}	1.3(14)
2858.88.....	0.910	Cr II	(5)	1.9(14)
2860.92.....	0.92	Cr II	(5)	2.1(14)
2862.55.....	0.57	Cr II	(5)	2.5(14)
2865.10.....	0.10	Cr II	(5)	3.9(14)
2866.73.....	0.72	Cr II	(5)	3.6(14)
2867.63.....	0.65	Cr II	(5)	2.6(14)
2868.81.....	0.874	Fe II	(61)	5.0(13)
2870.43.....	0.430	Cr II	(11)	1.6(14)

λ(Å) Solar (air)	λ(Å) Lab	Ion	Mul*	Flux† π(photons cm⁻² s⁻¹ sr⁻¹)
2873.41.....	{0.399 / 0.46}	Fe II / Cr II	(279) / (5)	1.7(14) / ...
2873.74.....	0.81	Cr II	(11)	7.5(13)
2875.35.....	0.342	Fe II	(258)	6.9(13)
2876.00.....	{5.97 / 0.24}	Cr II / Cr II	(11) / (5)	2.4(14)
2877.95.....	0.97	Cr II	(5)	6.0(13)
2880.79.....	{0.750 / 0.828}	Fe II / Fe II	(61) / (258)	1.6(14)
2889.18.....	0.190	Cr II	(11)	8.0(13)
2889.52.....	...	...	...	8.5(13)
2898.58.....	...	...	...	7.3(13)
2926.56.....	0.584	Fe II	(60)	1.5(14)
2933.06.....	0.051	Mn II	(5)	8.5(14)
2936.49.....	0.496	Mg II	(2)	1.2(14)
2939.31.....	0.302	Mn II	(5)	8.8(14)
2944.39.....	0.399	Fe II	(78)	3.4(14)
2947.65.....	0.658	Fe II	(78)	2.9(14)
2949.22.....	0.201	Mn II	(5)	1.0(15)
2953.74.....	0.774	Fe II	(60)	1.1(14)
2984.84.....	0.831	Fe II	(78)	4.0(14)
2985.54.....	0.545	Fe II	(78)	2.0(14)
3002.63.....	0.650	Fe II	(78)	2.0(14)
3066.26.....	{0.220 / 0.364}	Ti II / Ti II	(5) / (5)	1.2(14)
3072.96.....	0.971	Ti II	...	1.7(14)
3075.22.....	0.225	Ti II	(5)	1.7(14)
3078.66.....	0.645	Ti II	(5)	2.1(14)
3088.04.....	0.027	Ti II	(5)	3.0(14)
3095.57.....	...	OH	...	3.3(14)
3100.68.....	...	...	...	....
3102.32.....	0.295	V II	(1)	2.2(14)
3110.67.....	0.708	V II	(1)	1.1(14)
3118.61.....	0.652	Cr II	(5)	2.8(14)
3120.36.....	0.371	Cr II	(5)	2.8(14)
3124.98.....	0.978	Cr II	(5)	3.5(14)
3128.70.....	0.699	Cr II	(5)	1.3(14)
3132.07.....	0.058	Cr II	(5)	6.7(14)
3136.70.....	0.680	Cr II	(5)	1.2(14)
3147.98.....	8.033	Ti II	(4)	1.2(14)
3154.20.....	0.195	Ti II	(10)	1.6(14)
3161.18.....	0.205	Ti II	(10)	1.3(14)
3161.75.....	0.775	Ti II	(10)	1.3(14)
3162.59.....	0.570	Ti II	(10)	1.8(14)
3168.51.....	0.519	Ti II	(10)	2.3(14)
3179.32.....	0.332	Ca II	(4)	1.2(14)
3180.68.....	0.73	Cr II	(9)	2.3(14)
3186.72.....	0.740	Fe II	(6)	1.7(14)
3187.76.....	0.743	He I	(3)	5.1(14)
3190.87.....	0.874	Ti II	(26)	2.0(14)
3192.93.....	0.917	Fe II	(6)	1.1(14)
3193.78.....	0.809	Fe II	(6)	1.6(14)

NOTES TO TABLE 1

NOTE.—BL = blend, S = very strong line. Slightly more accurate wavelengths for the Ni II lines are given by Shenstone (1970).

* Multiplet from cited references to Moore's compilations.

† Fluxes are values at the Sun. True intensities in photons cm⁻² s⁻¹ sr⁻¹ are obtained by dividing the numbers in the table by π/1.7 (see text for discussion).

‡ Identification was suggested to us by Johansson (1975) based on his work or on the work of Dobbie (1938).

§ Identification was suggested to us by Kelly (1976).

of 1.5 if the Tousey *et al.* data are used. This difference is not significant because the pointing accuracy of the *Skylab* spectrograph was about 1″ (Bartoe *et al.* 1974). In 1′ the actual line intensities vary by at least a factor of 2 (see Fig. 2 and § IIIc).

b) *The Spectrum Recorded at +4″ above the Limb*

The lines observed in the quiet Sun spectrum recorded at +4″ above the limb are given in Table 1.

DOSCHEK, FELDMAN, AND COHEN
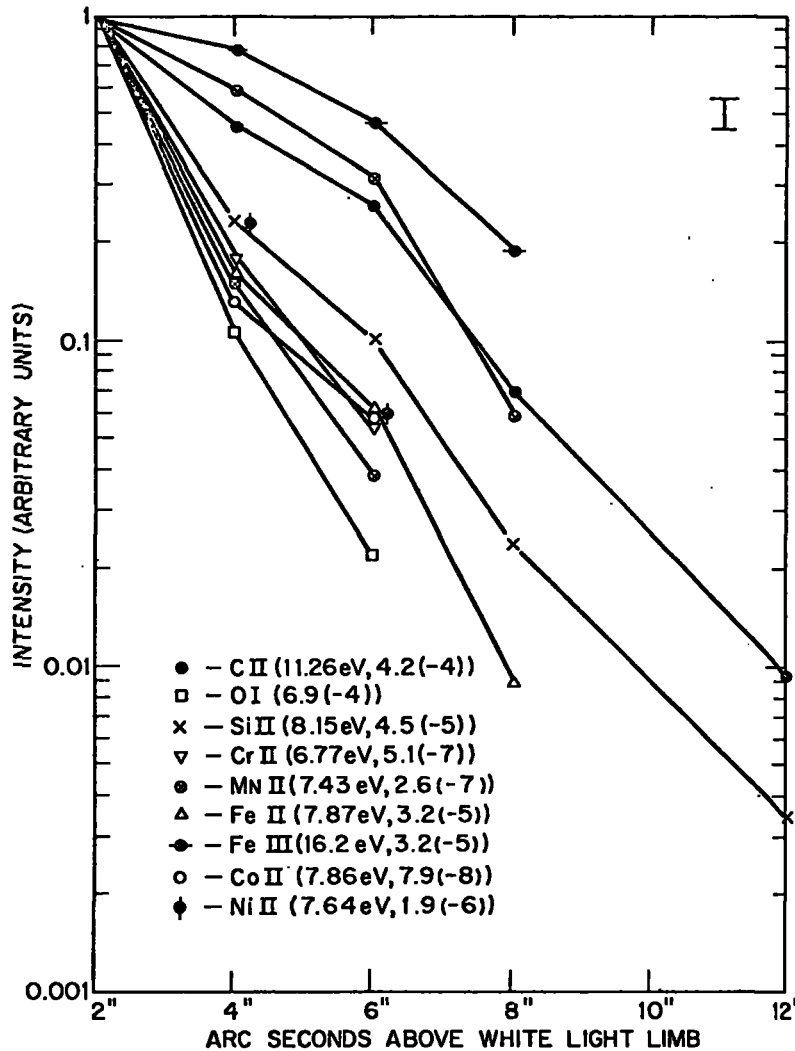
FIG. 2.—The intensity behavior of chromospheric ions above the limb. The data in parentheses are the ionization potential of the next lower stage of ionization (Kelly and Palumbo 1973) and the element abundance relative to hydrogen (Ross and Aller 1976). The Upper Mn II curve is derived from the $^7S-^7P$ lines (see text).

The solar wavelengths were obtained by a standard polynomial fitting procedure. The wavelength accuracy was found to be ±0.04 Å. The wavelength standards used to calibrate the spectra were lines of Fe II and Cr II. The laboratory wavelengths were obtained from the sources from which identifications were made. Most of the identifications were based on the compilations of Moore. These are the Ultraviolet Multiplet Tables (NBS Circular 488), the Selected Tables of Atomic Spectra (NSRDS-NBS 3), and A Multiplet Table of Astrophysical Interest (NBS Technical Note 36). A few identifications have been obtained from other unpublished sources. These are marked in the table. Moore's multiplet numbers are also given, as well as intensities derived as described above. In obtaining the line intensities, it was necessary to

perform the integration in equation (3). If a line is optically thin and has a Gaussian profile, $I_T{}^l$ in equation (3) is given by

$$I_T = \frac{1}{2}\left(\frac{\pi}{\ln 2}\right)^{1/2}\frac{I_0{}^l W}{R_\lambda}, \qquad (4)$$

where $I_0{}^l$ is the peak line intensity, R_λ is the instrumental response at line center, and W is the full width at half-maximum intensity. Most of the lines in Table 1 have some opacity, and therefore equation (4) does not strictly apply. However, at +4″ above the limb, the position for which we give intensities, the opacity of most of the lines is small and the line profiles are approximately Gaussian. We found empirically that $W = 9.4 \times 10^{-5}\lambda$ for most of the singly ionized

E.2.2 (FD) "The Emission Spectrum of a Hydrogen Balmer Series Observed Above the Solar Limb from Skylab II. Active Regions," U. Feldman and G. A. Doschek. Submitted to Ap. j.

TABLE 1 (FD)

Active Regions Observed

Active Region	McMath Plage No.	Time (UT)
A (31 May 1973) 357		$16^h55.2^m - 18^h20.8^m$
B (11 Aug 1973) 474		$18^h43.5^m - 20^h16.4^m$
C (29 Aug 1973) 488		$20^h36.2^m - 22^h13.6^m$

TABLE 2 (F.D)
PROPERTIES OF HYDROGEN BALMER LINES IN ACTIVE REGIONS ABOVE THE SOLAR LIMB

		ACTIVE REGION A						ACTIVE REGION B						ACTIVE REGION C					
		+2″		+4″		+6″		+2″		+4″		+6″		+2″		+4″		+6″	
m	λ(Å)	Int.*	Δλ†(Å)	Int.	Δλ(Å)	Int.	Δλ(Å)	Int.	Δλ(Å)	Int.	Δλ(Å)	Int.	Δλ(Å)	Int.	Δλ(Å)	Int.	Δλ(Å)	Int.	Δλ(Å)
9......	3835.38	...	...	22.0	0.39	...	...	...	...	16.3	0.42	3.0	0.47	...	...	17.1	0.42	3.8	0.50
10.....	3797.90	...	...	15.0	0.39	...	...	...	...	11.0	0.41	2.0	0.47	...	...	12.6	0.42	2.7	0.46
11.....	3770.63	...	...	...	...	...	...	...	...	6.6	0.37	1.3	0.37	...	...	10.0	0.42	1.8	0.46
12.....	3750.15	...	...	8.6	0.41	...	...	...	...	5.5	0.36	1.0	0.39	...	...	7.5	0.39	1.5	0.44
13.....	3734.37	...	...	6.3	0.41	...	...	...	...	4.1	0.37	0.9	0.42	...	...	6.4	0.41	1.5	0.48
14.....	3721.94	...	...	5.2	0.42	...	...	...	...	3.7	0.42	...	...	...	...	5.2	0.41	...	...
15.....	3711.97	...	...	3.5	0.37	...	...	...	...	3.0	0.42	...	...	49.0	0.33	4.5	0.41	...	...
16.....	3703.85	35.7	0.39	2.4	0.34	...	...	22.6	0.30	1.8	0.37	...	...	37.8	0.36	3.1	0.37	...	...
17.....	3697.15	28.7	0.36	2.1	0.34	...	...	20.2	0.32	1.9	0.36	...	...	32.3	0.37	2.9	0.37	...	...
18.....	3691.55	24.7	0.36	2.1	0.39	...	...	16.2	0.29	2.0	0.47	...	...	27.7	0.41	3.4	0.50	...	...
19.....	3686.83	19.5	0.36	2.1	0.44	...	...	15.0	0.32	1.5	0.41	...	...	24.4	0.41	2.5	0.51	...	...
20.....	3682.81	16.3	0.32	1.6	0.46	...	...	12.0	0.33	1.2	0.37	...	...	20.7	0.41	1.8	0.37	...	...
21.....	3679.35	13.6	0.32	1.5	0.47	...	...	12.0	0.36	1.0	0.37	...	...	19.2	0.45	1.8	0.44	...	...
22.....	3676.36	12.2	0.37	...	...	...	...	10.3	0.44BL‡	...	...	...	...	17.2	0.48	...	...	...	...
23.....	3673.76	9.9	0.34	...	...	...	...	7.9	0.39	...	...	...	...	14.5	0.50	...	...	...	...
24.....	3671.48	9.9	0.38BL	...	...	...	...	8.9	0.47BL	...	...	...	...	14.8	0.55BL	...	...	...	...
25.....	3669.46	8.1	0.37	...	...	...	...	6.7	0.43	...	...	...	...	11.9	0.50	...	...	...	...
26.....	3667.68	5.6	0.40	...	...	...	...	5.8	0.44	...	...	...	...	10.9	0.51	...	...	...	...
27.....	3666.10	5.5	0.42	...	...	...	...	5.3	0.46	...	...	...	...	8.4	0.53	...	...	...	...
28.....	3664.68	...	...	...	...	...	...	...	...	...	...	...	...	7.6	0.55	...	...	...	...
29.....	3663.40	4.9	0.52	...	...	...	...	5.2	0.55	...	...	...	...	8.3	0.64	...	...	...	...
30.....	3662.26	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
31.....	3661.22	...	...	...	...	...	...	4.2	0.56	...	...	...	...	...	...	...	...	...	...

* Intensity in units 10^3 ergs cm^{-2} — s^{-1} — sr^{-1} at the Sun.

† Δλ = ⟨FWHM⟩ of the line after correcting for instrumental width.

‡ BL = blend.

E. 3 Forbidden Lines

E.3.1 (SBT) "Forbidden Lines of the Solar Corona and Transition Zone 975 A - 3000 A," G. D. Sandlin, G. E. Brueckner and R. Tousey. Submitted to Ap. J.

TABLE I (SBT)

FORBIDDEN LINES OF $5 \times 10^4 - 3 \times 10^6$ K PLASMA**

λ (Å)	σ	Class	Identification	Int. 4"	Int. 40"	FWHM 4"	FWHM 40"
974.86	.05		Fe XVIII $2s^2 2p^5$ $(^2P_{3/2} - {}^2P_{1/2})$				
997.1 •	.1		Ne VI $2s^2 2p$ $^2P_{1/2} - 2s2p^2$ $^4P_{1/2}$				
999.2 •	.1		Ne VI $^2P_{3/2} - {}^4P_{5/2}$				
1005.7 •	.1		Ne VI $^2P_{3/2} - {}^4P_{3/2}$				
1010.2 •	.1		Ne VI $^2P_{3/2} - {}^4P_{1/2}$				
1118.07	.05		Fe XIX $2s^2 2p^4$ $(^3P_2 - {}^3P_1)$				
1136.51	.02	II	Ne V $2s^2 2p^2$ $^3P_1 - 2s2p^3$ $^5S_2$				
1145.61	.02	II	Ne V $^3P_2 - {}^5S_2$				
1174.72#	.05	>IV	Ni XIV $3s^2 3p^3$ $(^4S_{3/2} - {}^2P_{1/2})$		0.24		
1189.82	.01	IV	Mg VII $2s^2 2p^2$ $(^3P_1 - {}^1S_0)$	2.5	1.9		.18
1190.07	.01	III	Mg VI $2s^2 2p^3$ $(^4S_{3/2} - {}^2P_{3/2})$		3.8		.18
1191.62	.02	III	Mg VI $(^4S_{3/2} - {}^2P_{1/2})$		0.75		.18
1196.24	.01	V	S X $2s^2 2p^3$ $(^4S_{3/2} - {}^2D_{5/2})$		0.45		.17
1199.18	.01	II	S V $3s^2$ $^1S_0 - 3s3p$ $^3P_1$	18.	0.11	.24	.12
1212.96	.01	V	S X $2s^2 2p^3$ $(^4S_{3/2} - {}^2D_{3/2})$	4.8	1.4	.26	.17
1213.90	.05	II+	O V† $2s^2$ $^1S_0 - 2s2p$ $^3P_2$				
1216.43	.01	VI	Fe XIII $3s^2 3p^2$ $(^3P_1 - {}^1S_0)$	6.0	5.8		
1218.35	.02	II+	O V $2s^2$ $^1S_0 - 2s2p$ $^3P_1$	36.	1.2	.22	.15
1232.62	.02	V			0.29		.17
1242.00	.01	VI-	Fe XII $3s^2 3p^3$ $(^4S_{3/2} - {}^2P_{3/2})$	10.0	10.0	.19	.17
1271.62	.02	>V			0.03		
1277.23	.01	VI	Ni XIII $3s^2 3p^4$ $(^3P_1 - {}^1S_0)$	0.51	0.12	.21	.18
1307.65	.02				0.02		
1322.2 #			Mn XII $3s^2 3p^2$ $(^3P_1 - {}^1S_0)$		0.01		
1324.44	.01	III	Mg V $2s^2 2p^4$ $(^3P_1 - {}^1S_0)$		0.09		.20
1331.52	.03		Ar XIII† $2s^2 2p^2$ $(^3P_1 - {}^1D_2)$				
1349.40	.01	VI-	Fe XII $3s^2 3p^3$ $(^4S_{3/2} - {}^2P_{1/2})$	5.1	6.7	.19	.17
1351.92	.01		F IV† $2s^2 2p^2$ $^3P_1 - 2s2p^3$ $^5S_2$				
1354.08	.05		Fe XXI $2s^2 2p^2$ $(^3P_0 - {}^3P_1)$				
1359.05	.01		F IV† $2s^2 2p^2$ $^3P_2 - 2s2p^3$ $^5S_2$				
1359.57	.02	V	Mn XI $3s^2 3p^3$ $(^4S_{3/2} - {}^2P_{3/2})$		0.06		.19
1368.83	.02	>V			0.04		.17
1370.52	.02	>V			0.04		.19
1375.95	.03	VI	Ca XV† $2s^2 2p^2$ $(^3P_2 - {}^1D_2)$		0.04		
1392.12	.01	VI	Ar XI $2s^2 2p^4$ $(^3P_2 - {}^1D_2)$		0.10		.22
1397.22	.02	II	O IV $2s^2 2p$ $^2P_{1/2} - 2s2p^2$ $^4P_{3/2}$	2.0	0.02	.23	
1399.78	.01	II	O IV $^2P_{1/2} - {}^4P_{1/2}$	6.6	0.06	.23	.15
1401.17	.01	II	O IV $^2P_{3/2} - {}^4P_{5/2}$	28.	0.44	.23	.15
1404.80	.02	II	O IV $^2P_{3/2} - {}^4P_{3/2}$	13.	0.18	.23	.15
			S IV $3s^2 3p$ $^2P_{1/2} - 3s3p^2$ $^4P_{1/2}$				
1406.06	.01	II	S IV $^2P_{3/2} - {}^4P_{5/2}$	6.0	0.03	.23	
1407.39	.02	II	O IV $2s^2 2p$ $^2P_{3/2} - 2s2p^2$ $^4P_{1/2}$	6.8	0.05	.23	
1408.65	.03	V		0.28	0.07		.17
1409.45	.01	V+		0.37	0.19		.19
1416.93	.01		S IV $3s^2 3p$ $^2P_{3/2} - 3s3p^2$ $^4P_{3/2}$	3.4	0.02		
1423.89	.01		S IV $3s^2 3p$ $^2P_{3/2} - 3s3p^2$ $^4P_{1/2}$	0.28			
1428.76	.01	>V		0.85	0.84	.21	.16
1440.01#	.02		Cr XI $3s^2 3p^2$ $(^3P_1 - {}^1S_0)$		0.03		
1440.50	.01	IV	Si VIII $2s^2 2p^3$ $(^4S_{3/2} - {}^2D_{5/2})$		0.18		.22
1445.76	.01	IV	Si VIII $2s^2 2p^3$ $(^4S_{3/2} - {}^2D_{3/2})$	1.1	3.70	.24	.22
1450.49	.05		Mn XI $3s^2 3p^3$ $(^4S_{3/2} - {}^2P_{1/2})$				
1463.49	.01	V-	Fe X† $3p^4 3d$ $(^4F_{9/2} - {}^2F_{7/2})$	2.3	0.72	.15	.17
1467.06	.01	V	Fe XI $3s^2 3p^4$ $(^3P_1 - {}^1S_0)$	4.3	2.2	.17	.16

λ (Å)	σ	Class	Identification	Int. 4"	Int. 40"	FWHM 4"	FWHM 40"
1467.44	.03		P IV $3s^2$ $^1S_0 - 3s3p$ $^3P_1$				
1486.52	.02		N IV $2s^2$ $^1S_0 - 2s2p$ $^3P_1$	11.	0.12	.23	.19
1489.04	.03	V	Cr X $3s^2 3p^3$ $(^4S_{3/2} - {}^2P_{3/2})$		0.09		.20
1510.51	.03	>V			0.04		
1564.30	.02	>V	Cr X $3s^2 3p^3$ $(^4S_{3/2} - {}^2P_{1/2})$		0.05		
1574.9		III	Ne V $2s^2 2p^2$ $(^3P_1 - {}^1S_0)$		0.05		
1582.56	.04	>V	Ar XIII† $2s^2 2p^2$ $(^3P_2 - {}^1D_2)$		0.36		.22
1601.5, .7		II	Ne IV $2s^2 2p^3$ $(^4S_{3/2} - {}^2P_{3/2}, {}^2P_{1/2})$				
1603.21	.01	IV	Fe X† $3p^4 3d$ $(^4D_{7/2} - {}^2G_{7/2})$	0.5	1.5		.34
1611.70	.05	V		0.4	0.26		.27
1614.51	.03	VI	S XI $2s^2 2p^2$ $(^3P_1 - {}^1D_2)$	0.4	0.74		.26
1623.54	.04	IV-VI	O VII $1s2s$ $^3S_1 - 1s2p$ $^3P_2$	0.4	0.25		
1639.78	.03	IV-VI	O VII $^3S_1 - {}^3P_0$	1.0	0.68		
1640.65	.03				0.27		
1660.81	.01	I	O III $2s^2 2p^2$ $^3P_1 - 2s2p^3$ $^5S_2$	16.		.21	
1666.16	.01	I	O III $^3P_2 - {}^5S_2$	41.		.21	
1666.95	.01				0.08		.23
1696.26	.05				0.06		
1715.44	.01	IV+	S IX $2s^2 2p^4$ $(^3P_2 - {}^1D_2)$	1.2	0.50		.26
1717.42	.02	V	Ni XI $3s^2 3p^5 3d$ $(^3P_2 - {}^3D_2)$		0.15		.21
1746.81	.02	I	N III $2s^2 2p$ $^2P_{1/2} - 2s2p^2$ $^4P_{3/2}$	10.			.23
1748.63	.02	I	N III $^2P_{1/2} - {}^4P_{1/2}$	4.4			
1749.67	.01	I	N III $^2P_{3/2} - {}^4P_{5/2}$	18.	0.02	.23	
1752.14	.01	I	N III $^2P_{3/2} - {}^4P_{3/2}$	2.7			
1753.98	.01	I	N III $^2P_{3/2} - {}^4P_{1/2}$	5.4		.23	
1756.82	.03	I-	P III $3s^2 3p$ $^2P_{1/2} - 3s3p^2$ $^4P_{1/2}$				
1757.64	.03	I-	P III $^2P_{3/2} - {}^4P_{5/2}$				
1805.94	.03		Mg VI $2s^2 2p^3$ $(^4S_{3/2} - {}^2D_{3/2})$		0.06		
1826.21	.02	VI	S XI $2s^2 2p^2$ $(^3P_2 - {}^1D_2)$	2.8	0.28	.21	.28
1841.57	.02	IV	Fe IX $3s^2 3p^5 3d$ $(^3P_1 - {}^3D_2)$		0.23		.27
1847.25	.02	VI		1.7	0.20		.29
1866.75	.01	VI	Ni XIV $3s^2 3p^3$ $(^4S_{3/2} - {}^2D_{5/2})$	1.3	0.35		.29
1892.03		I-	Si III $3s^2$ $^1S_0 - 3s(^2S)3p$ $^3P_1$	440.	2.1		.08
1908.73	.01	I-	C III $2s^2$ $^1S_0 - 2s2p$ $^3P_1$	71.	0.67		.19
1917.21	.02	IV	Fe IX $3s^2 3p^5 3d$ $(^3P_2 - {}^1F_3)$		0.48		.28
1918.25	.01	V-	Fe X† $3s^2 3p^4 3d$ $(^4D_{7/2} - {}^2F_{7/2})$	2.7	1.1		.24
1984.88	.02	IV+	Si IX $2s^2 2p^2$ $(^3P_1 - {}^1D_2)$	6.6			.38
2000.4 §			Ni XI $3s^2 3p^5 3d$ $(^3F_4 - {}^1F_3)$				
2042.35	.01	IV	Fe IX $3s^2 3p^5 3d$ $(^3P_2 - {}^3D_2)$	12.			.38
2085.51	.05	VI	Ni XV $3s^2 3p^2$ $(^3P_1 - {}^1D_2)$	6.7			.40
2125.50	.02	VI-	Ni XIII $3s^2 3p^4$ $(^3P_2 - {}^1D_2)$	12.			.35
2146.64	.04	III	Si VII $2s^2 2p^4$ $(^3P_2 - {}^1D_2)$	2.0			.35
2149.26	.05	IV+	Si IX $2s^2 2p^2$ $(^3P_2 - {}^1D_2)$	11.			.43
2169.08	.02	VI-	Fe XII $3s^2 3p^3$ $(^4S_{3/2} - {}^2D_{5/2})$	29.			.33
2184.26	.05	VI	Ni XIV $3s^2 3p^3$ $(^4S_{3/2} - {}^2D_{3/2})$	14.			.32
2405.68	.01	VI-	Fe XII $3s^2 3p^3$ $(^4S_{3/2} - {}^2D_{3/2})$	150.			.37
2497.5			Fe IX $3s^2 3p^5 3d$ $(^3F_4 - {}^1F_3)$	~10.			
2565.93	.06	VI-	Fe XII $3s^2 3p^3$ $(^2D_{3/2} - {}^2P_{3/2})$	43.			.39
2570.14	.02			28.			.38
2578.77	.01	VI	Fe XIII $3s^2 3p^2$ $(^3P_1 - {}^1D_2)$	160.			.40
2622.56	.05			19.			.42
2648.71	.02	V	Fe XI $3s^2 3p^4$ $(^3P_2 - {}^1D_2)$	97.			.38

Notes to Table I *(57 7)*

*   Observed in the NRL rocket spectrum of 1966 July 27.

†   Tentative identification.

Observed only in the 36-minute exposure of Figure 3.

§   Blended with Fe II 2000.3 Å. Wavelengths above 2000 Å are in air.

**   Three flare lines of higher temperature are included for completeness.

Ionization Class	Log T_e
I	4.7 - 5.0
II	5.0 - 5.3
III	5.3 - 5.6
IV	5.6 - 5.9
V	5.9 - 6.1
VI	6.1

The columns INT. and FWHM refer, respectively, to observations above AR 12114 at 4" above the limb, and above AR 12300 at 40" above the limb.

To be Typed

19